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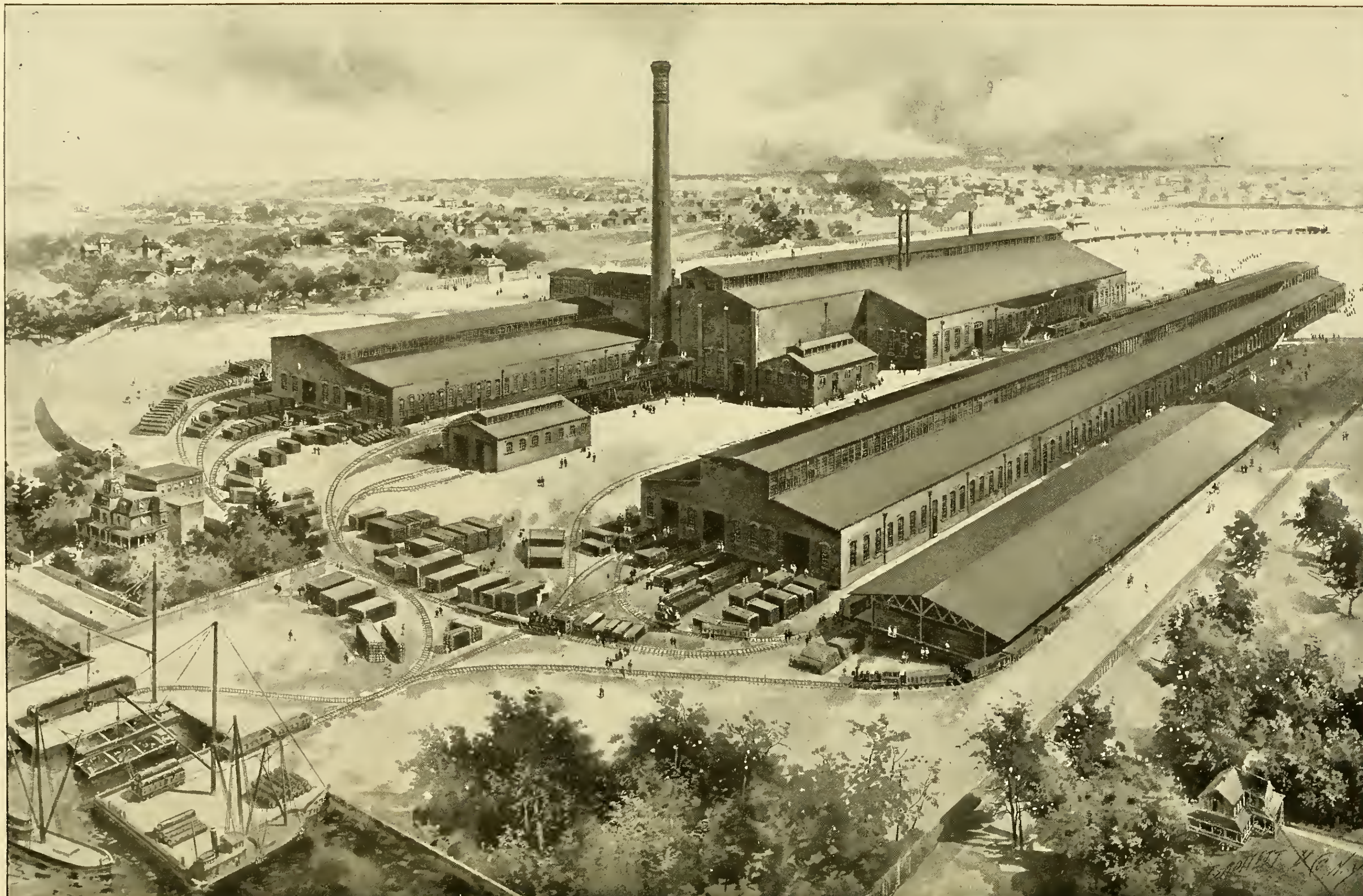

Works of The Babcock & Wilcox Company at Bayonne, N. J.

STEAM

ITS GENERATION AND USE

WITH CATALOGUE OF THE
MANUFACTURES OF

THE BABCOCK & WILCOX CO.

85 LIBERTY ST., NEW YORK

AND

BABCOCK & WILCOX, LIMITED

ORIEL HOUSE, FARRINGDON ST., LONDON

THIRTY-THIRD EDITION
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ECONOMY AND SAFETY IN STEAM GENERATION.

ECONOMY IN THE USE OF COAL is a matter of great and growing importance. It is estimated that the annual production of coal of the world for the year 1896 was 583,450,131 tons, the leading producing countries being :

United Kingdom,	195,272,000
United States,	168,957,264
Germany,	112,437,741
France,	28,870,091
Austria-Hungary,	28,125,000
Belgium,	21,250,000
Russia,	7,785,000

The report of the Royal Commission in England in 1870 shows the distribution at that time to have been as follows :

Metallurgy and mines,	44 per cent.
Domestic purposes, including gas and water,	26 " "
General manufacturing,	25 " "
Locomotion by sea and land,	5 " "

Since 1870 the electrical industries have been established, employing an enormous amount of power, so that the foregoing percentages are probably very different at the present time, and as a considerable part of the coal used in metallurgy and mines, as also that for domestic water supply, is used for power, we shall not be far wrong in estimating that 300,000,000 tons are used annually for making steam. A low estimate of the value of this coal at the place of use would be an average of $2.50 per ton, which gives as the present annual expenditure for steam a sum equal to $750,000,000 ; from which it will be seen how largely even a small per cent. of saving would add to the wealth of the world.

It is estimated that of the steam-power at present in use in the world, 80 per cent. has been added in the last twenty-five years, so that these figures are none too large for the present time.

While manufacturers and engineers have given much care to the improvement of the steam engine, whereby they might reduce the consumption of steam for a given amount of power, but little attention, comparatively, has been given to securing economy in its generation. In fact, a large number of the boilers in use at the present day are substantially the same as were in common use at the close of the last century, and but slight advance has been made in their economy. Of late years, however, steam users have begun to realize that there are principles and aims of equal prominence, and greater importance, to be considered in choosing a boiler, to the selection of a steam engine.

Engineering experience and scientific investigation have established the following as the

Requirements of a Perfect Steam Boiler.

1st. The best materials sanctioned by use, simple in construction, perfect in workmanship, durable in use, and not liable to require early repairs.

2d. A mud-drum to receive all impurities deposited from the water in a place removed from the action of the fire.

3d. A steam and water capacity sufficient to prevent any fluctuation in pressure or water level.

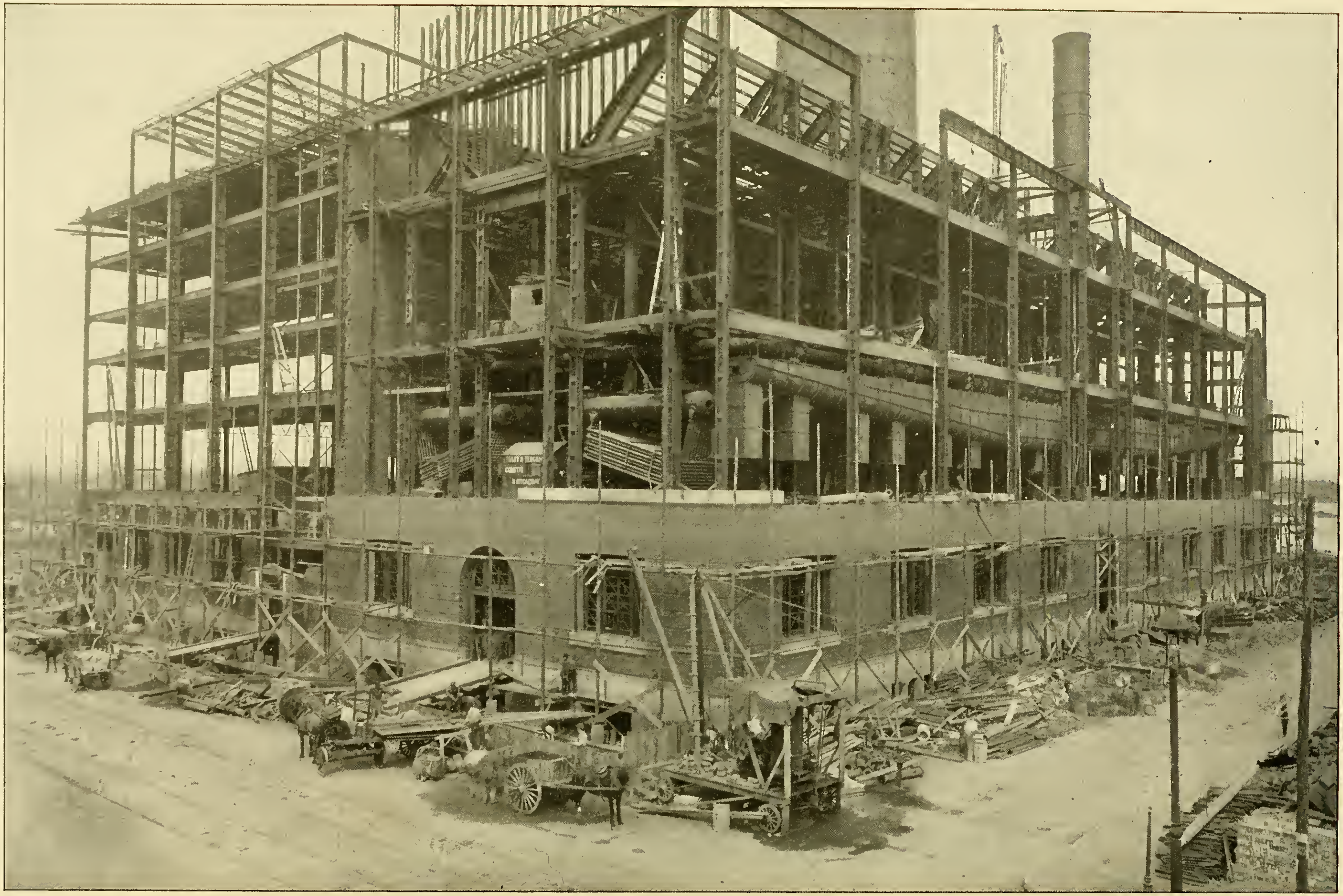
4th. A large water surface for the disengagement of the steam from the water in order to prevent foaming.

5th. A constant and thorough circulation of water throughout the boiler, so as to maintain all parts at one temperature.

6th. The water space divided into sections, so arranged that, should any section give out, no general explosion can occur, and the destructive effects will be confined to the simple escape of the contents ; with large and free passages between the different sections to equalize the water line and pressure in all.

7th. A great excess of strength over any legitimate strain ; so constructed as not to be liable to be strained by unequal expansion, and, if possible, no joints exposed to the direct action of the fire.

8th. A combustion chamber so arranged that the combustion of the gases commenced in the furnace may be completed before the escape to the chimney.



96th Street Power Station, Metropolitan Street Railway Co. 25,000 H. P. Babcock & Wilcox Boilers on three floors. 60,000 H. P. in the various stations of this Company and its leased lines.

9th. The heating surface as nearly as possible at right angles to the currents of heated gases, and so as to break up the currents and extract the entire available heat therefrom.

10th. All parts readily accessible for cleaning and repairs. This is a point of the greatest importance as regards safety and economy.

11th. Proportioned for the work to be done, and capable of working to its full rated capacity with the highest economy.

12th. The very best gauges, safety valves, and other fixtures.

Importance of Providing Against Explosion.

That the ordinary forms of boilers are liable to explode with disastrous effect is conceded. That they do so explode is witnessed by the sad list of casualties from this cause every year, and almost every day. In the year 1880, there were 170 explosions reported in the United States, with a loss of 259 lives, and 555 persons injured. In 1887 the number of explosions recorded were 198, with 652 persons either killed or badly wounded. The average reported for ten years past has been about the same as the two years given, while doubtless many occur which are not recorded.

There is no need to resort to mysterious causes for the destructive energy displayed in a boiler explosion, for there is ample force confined within it to account for all the phenomena. Prof. Thurston* estimates that there is sufficient stored energy in a plain cylinder boiler with 100 pounds pressure of steam to project it to a height of over three and one-half miles; a "two-flue" boiler about two and one-half miles; a "locomotive" at 125 pounds from one-half to two-thirds of a mile; and a 60 H.P. return "tubular" at 75 pounds somewhat over a mile high. He says, "A cubic foot of heated water under a pressure of 60 to 70 pounds per square inch, has *about the same energy as one pound of gunpowder*. At a low, red heat, it has *about forty* times this amount of energy in a form to be so expended." Speaking of water-tube boilers he says: "The stored available energy is usually less than that of any of the other stationary boilers, and not very far from the amount stored, pound for pound, in the plain tubular boiler. It is evident that their admitted safety from destructive explosion does not come from this relation, however, but from the division of the contents into small portions, and especially from those details of construction which make it tolerably certain that any rupture shall be local. A violent explosion can only come of the general disruption of a boiler and the liberation at once of large masses of steam and water."

*Transactions Am. Soc. Mec. Eng., Vol. 6, page 199.

The Hartford Steam Boiler Inspection and Insurance Company report that up to January 1, 1888, they had inspected, in all, 799,582 boilers, and had discovered 522,873 defects, *of which 93,022 were considered dangerous*. If now the above were a fair average of the boilers in ordinary use—and who shall say they are not?—we have the startling fact that *more than one boiler in nine* in common use is in a "dangerous condition." That more do not explode is probably due less to intelligent watchcare than to the fortunate lack of all the necessary conditions existing at one time.

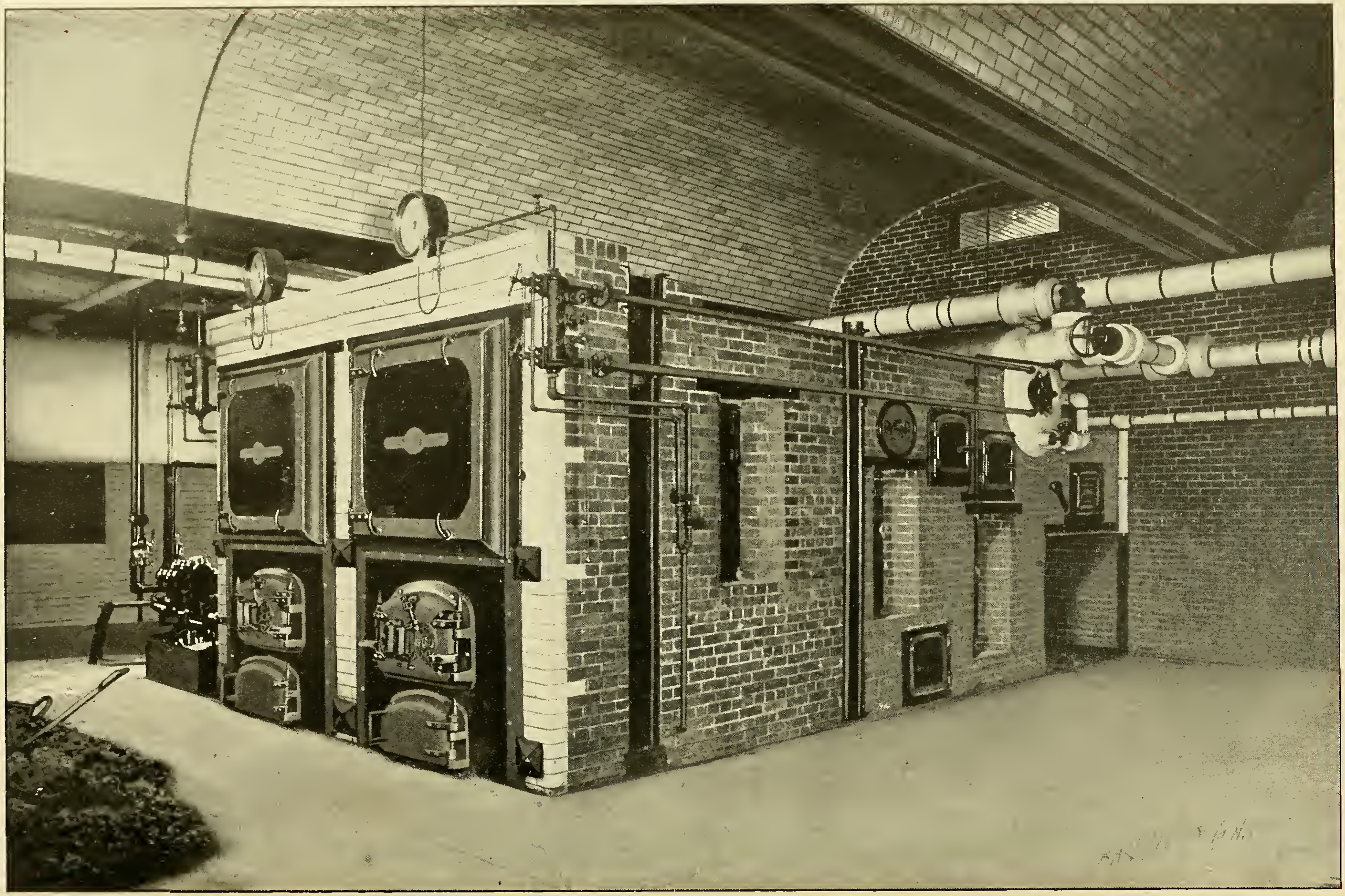
Causes of Explosion.

It is now fully established by the experience of Boiler Insurance Associations in this country and England, that all the mystery of boiler explosions consists in a want of sufficient strength to withstand the pressure. This lack of strength may be inherent in the original construction, but is most frequently the effect of weakening of the iron by strains due to unequal expansion caused by unequal heating of different portions of the boiler; or it may be due to corrosion from long use or improper setting.

If steam boilers are properly proportioned and constructed, they will, when new, be safe against considerably more pressure than the safety valve is set to; and the hydrostatic test, properly applied, may discover faults in material, or the weakening effects of corrosion; but, against the danger resulting from unequal expansion, ordinary boilers have no protection; a fact not properly appreciated by engineers or the public.

In getting up steam many boilers will be very hot in some parts, while other parts will be actually cold; of course, under these conditions, enormous strains must occur in some portions of the boiler, which are thereby weakened; and these strains being repeated every time steam is raised, if at no other time, will eventually so far destroy the strength of the line or point of greatest strain that rupture must result; generally the rupture is small and gradual, but sometimes large and productive of disastrous explosions. In the boilers examined by the Hartford Boiler Insurance Company, up to 1888, 24,944 fractures in plates were found in, at, or near the seams or through the line of rivets, 11,259 of which, or nearly one half, had arrived at a dangerous state before discovery.

Want of circulation of the water in boilers is a frequent and prolific cause of unequal expansion, and deteriorating strains, and little, if any, provision is made for circulation in all ordinary construction of boilers. Another source of dan-



Babcock & Wilcox Boilers, Cross Drum Type. 200 H. P. in Back Bay Passenger Station, Boston, Mass., New York, New Haven and Hartford R. R. Co.

ger in all ordinary boilers is low water; and constant vigilance is required to keep the water at a proper height. In many boilers the fall of only a few inches in the water-line will cause the crown-sheet or some other portion to be exposed to the direct action of the fire, whence it becomes quickly overheated, and weakened to such an extent that an explosion is likely to occur.

Another frequent cause of unequal expansions, and also of weakening by burning and blistering the iron, is the presence of deposit or scale on the heating surface. This is liable to occur in any boiler, but in very many there is no adequate provision for removing it when formed. This is particularly the case with "tubular" and "locomotive" boilers.

There is good reason for believing that most of the mysterious explosions of boilers which stand the Inspector's test, and then explode at a much less pressure, are due to the weakening effects of unequal expansions, for a boiler that will stand a hundred pounds test this week cannot explode the next week at fifty pounds pressure, unless it has suddenly become wonderfully reduced in strength, and no corrosion or other natural cause, with which we are acquainted, save expansion, can produce this result. When we consider that strains from difference of expansion are generally greatest when firing up, and when there is no pressure in the boiler, we can see that the time may arrive when a crack is started or the parts weakened, so as to give way under a moderate pressure just after the test has been made; and this is the probable reason why so many boilers explode in getting up steam, or so soon after, or upon pumping in cold water, or, even, as in a recent case in England, while cooling off.

How to Provide Against Explosions.

Very much thought and experiment have been expended on this problem, but though many forms of boilers have been produced, which have attained practical safety from explosion, yet in nearly all of them there have been ignored certain elements necessary at the same time to make them valuable as generators of steam for practical work. Hence, the very name of "safety boiler" has unfortunately become, to some persons, *prima facie* evidence of undesirability. But safety is not incompatible with any of the other essentials of a perfect steam generator, and may be secured without detracting from any other desirable feature.

The first element of safety is ample strength. This can be best attained in connection with thin heating surface, by small diameters of parts; but this must not be carried so far as to antagonize the equally important features of large capacity and disengaging surface.

The second and most important element of safety is such a structure that the original strength cannot be destroyed by deteriorating strains, from expansion or otherwise. This can be attained in two ways—by rendering unequal expansion impossible, or by providing such elasticity that, should it occur, it can produce no deteriorating strain.

The third element of safety is such an arrangement of parts that when, through gross carelessness or design, the water becomes low and the boiler overheated, a rupture, if it occur, can produce no serious disaster.

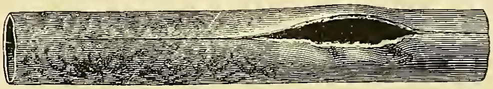
No surface which requires to be "stayed" should be permitted in a boiler. It is scarcely possible, and altogether improbable, that such stays are, or can be, so adjusted as to bear equal strains. The one sustaining the heaviest strain gives way, the others follow, as a matter of course, and a disastrous explosion ensues. The photographic view of the boiler which exploded at Washington, January 9, 1888, shows how stay bolts act, and the disastrous explosion at West Chester, Pa., about the same time, was clearly due to the giving way of the stays which were intended to support the head.

Water-tubes an Element of Safety.

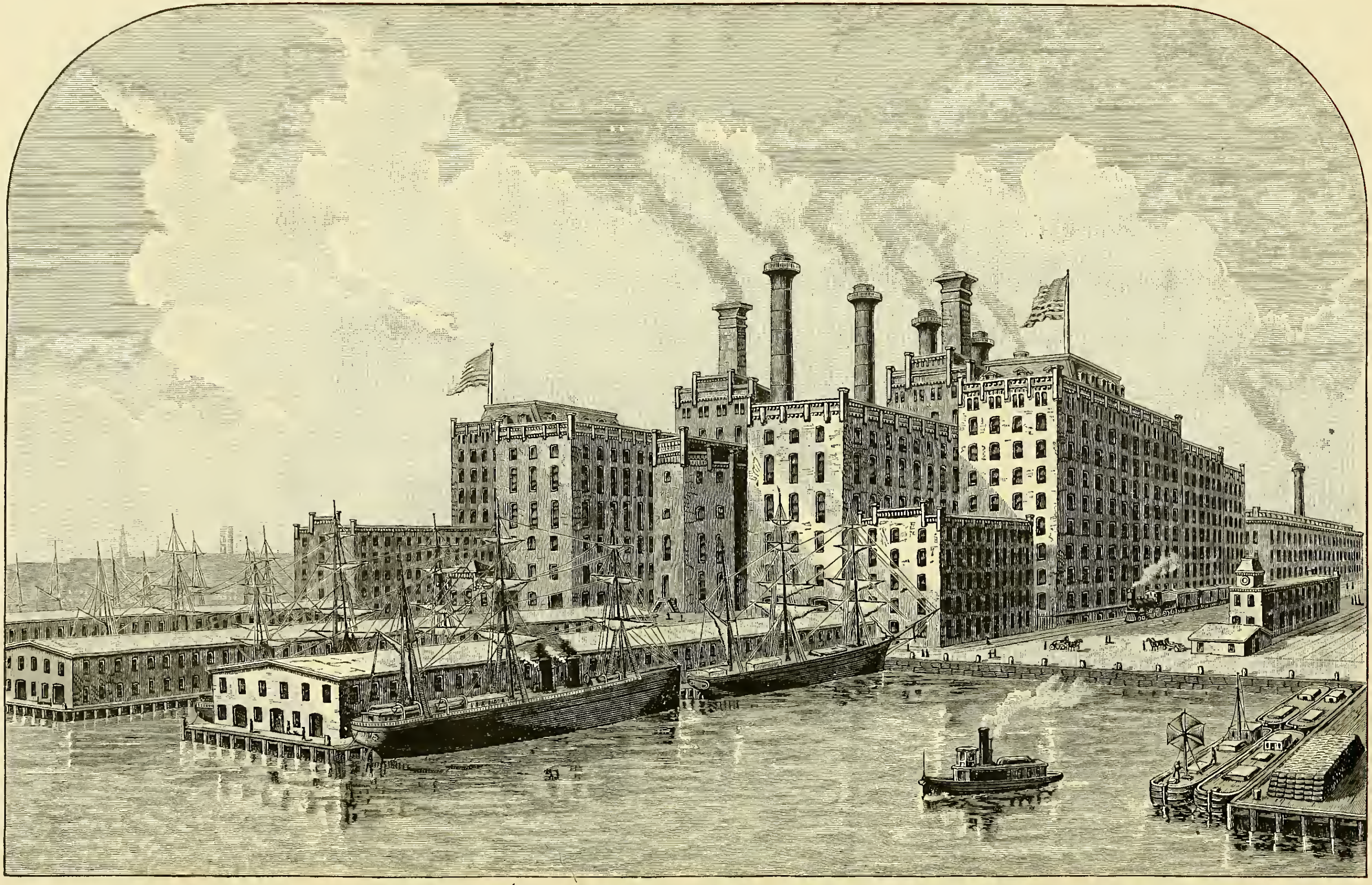
[*From the Manufacturer and Builder, Feb., 1880.*]

Some recent actual occurrences have a very suggestive bearing upon the relative degree of immunity from violent and disastrous explosions possessed by the water-tube and fire-tube systems of boiler construction respectively.

The first case is that of an accident resulting through gross carelessness to a steam boiler on the water-tube system as constructed by Messrs. Babcock & Wilcox. The circumstances of the case were such as to make the test to which the boiler was put a most severe one, and the fact that the result was *not* a disastrous explosion scores several points in favor of the water-tube system.



The boiler here referred to is located in the Brooklyn Sugar Refinery, and is rated at 300 horse-power, being one of a set of 1500 H. P. Recently, by one of those oversights that now and then cost scores of lives under the same circumstances, the feed-water was cut off, and not noticed until the water level became so low that



American Sugar Refining Co's Spreckels Refinery, Philadelphia. 9000 H.P. Babcock & Wilcox Boilers in use. 62,000 H.P. in various Refineries of this Company.

the boiler was nearly empty and the tubes were overheated. The result is shown above. One of the tubes burst, and this was the extent of the damage, which was speedily repaired at a cost of $15, and the works were running the next day.

The second case is very analogous, but is even more instructive, as the boiler was subjected to a severer ordeal than the other. This boiler is in the Elizabeth (N. J.) jail, and was one of the same kind as that in the foregoing case. It was in charge of one of the convicts, who, after starting the fire as usual in the morning, was surprised not to observe, after an hour or so of waiting, any signs of activity in his steam gauge. This fact was disclosed to some of the officials of the prison, and an investigation was instituted to ascertain the cause, disclosing a fact that at once relieved the boiler from any responsibility for the absence of steam—for there was no water in it. It also showed that the blow-cock was wide open, and had been since the night before. What followed, we give in Mr. Watson's own words:

"After the syndicate had opened the furnace door and seen the white hot tubes, it was thought a good idea to get some water in the boiler as quickly as possible; so they shut the blow-cock and turned on the city water. The result justified their expectations; steam was made very quickly; for a moment it roared through the safety valve with a fearsome sound; and that is all that happened, beyond the renewal of a few of the tubes, and one steel casting."

What might have happened had either of these boilers been fire-tube instead of water-tube boilers, we do not pretend to say, but think Mr. Watson is not far out of the way in venturing the statement that "it is not contrary to precedent to say that, in all probability, there would have been an opportunity for a coroner's inquest and a new jail."

Caution Necessary.

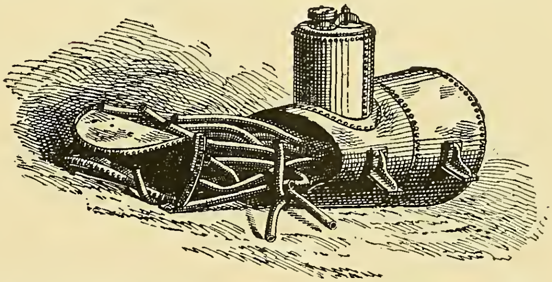
It must not be assumed, however, that the mere presence of water tubes in a boiler will make it safe. On the contrary, they may be combined with other features exceedingly dangerous, such as flat surfaces, stayed or unstayed, as in the "Phleger" boiler which exploded in Philadelphia some years ago, and the "Firminich" boiler which exploded in St. Louis, Oct. 3d, 1887. A number of porcupine boilers have also been put forth as "safe" because of their water tubes, though the large central shell is made like perforated cardboard, by the numerous holes. To make the matter worse, expanding the tubes into these holes seriously strains the metal, making a weak construction weaker still.

That a boiler can be made so as to be practically safe from explosion is a demonstrated fact of which no one at all acquainted with modern engineering has any doubt. Of this class of boilers the Babcock & Wilcox is a pre-eminent example, from the length of time which it has been upon the market, the large number which have been for years in use under all sorts of circumstances and conditions and under all kinds of management, without a single instance of disastrous explosion.

The Babcock & Wilcox water-tube boiler has all the elements of safety, in connection with its other characteristics of economy, durability, accessibility, etc. Being composed of wrought iron tubes, and a drum of comparatively small diameter, it has a great excess of strength over any pressure which it is desirable to use. As the rapid circulation of the water insures equal temperature in all parts, the strains due to unequal expansion cannot occur to deteriorate its strength. The construction of the boiler, moreover, is such that, should unequal expansion occur under extraordinary circumstances, no objectionable strain can be caused thereby, ample elasticity being provided for that purpose in the method of construction.

In this boiler, so powerful is the circulation that as long as there is sufficient water to about half fill the tubes, a rapid current flows through the whole boiler; but if the tubes should finally get almost empty, the circulation then ceases and the boiler might burn and give out; by that time, however, it is so nearly empty as to be incapable of harm if ruptured.

Its successful record of over thirty years proves that by the application of correct principles, the use of proper care and good material in construction, a boiler can be made so as to be in fact as well as in name a "safety boiler."



Return Tubular Boiler at the Edison Electric Light Co.'s Works, West Chester, Pa.
Exploded Dec. 17, 1887, killing seven and wounding eight people.

Vienna Opera House, Vienna, Austria. Lighted by Electricity. Power furnished by 1,192 H.P. of Babcock & Wilcox Boilers.

THE THEORY OF STEAM MAKING.

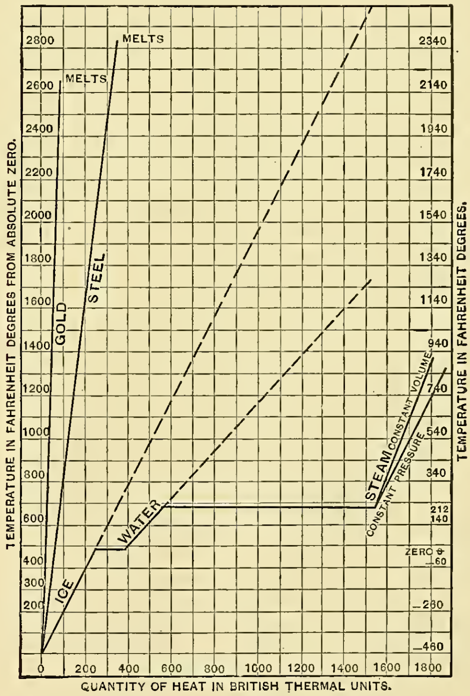
[Extracts from a Lecture delivered by Geo. H. Babcock, at Cornell University, 1887.*]

The chemical compound known as H_2O exists in three states or conditions—ice, water, and steam ; the only difference between these states or conditions is in the presence or absence of a quantity of energy exhibited partly in the form of heat and partly in molecular activity, which, for want of a better name, we are accustomed to call "latent heat"; and to transform it from one state to another we have only to supply or extract heat. For instance, if we take a quantity of ice, say one pound, at absolute zero† and supply heat, the first effect is to raise its temperature until it arrives at a point 492 Fahrenheit degrees above the starting point. Here it stops growing warmer, though we keep on adding heat. It, however, changes from ice to water, and when we have added sufficient heat to have made it, had it remained ice, 283° hotter or a temperature of 315° by Fahrenheit's thermometer, it has all become water, at the same temperature at which it commenced to change, namely, 492° above absolute zero, or 32° by Fahrenheit's scale. Let us still continue to add heat, and it will now grow warmer again, though at a slower rate—that is, it now takes about double the quantity of heat to raise the pound one degree that it did before—until it reaches a temperature of 212° Fahrenheit, or 672° absolute (assuming that we are at the level of the sea). Here we find another critical point. However much more heat we may apply, the water, as water, at that pressure, cannot be heated any hotter, but changes on the addition of heat to steam ; and it is not until we have added heat enough to have raised the temperature of the water 966°, or to 1,178° by Fahrenheit's thermometer (presuming for the moment that its specific heat has not changed since it became water), that it has all become steam, which steam, nevertheless, is at the temperature of 212°, at which the water began to change. Thus over four fifths of the heat which has been added to the water has disappeared, or become insensible in the steam to any of our instruments.

It follows that if we could reduce steam at atmospheric pressure to water, without loss of heat, the heat stored within it would cause the water to be *red hot;* and if we could further change it to a solid, like ice, without loss of heat, the solid would be white hot, or hotter than melted steel—it being assumed, of course, that the specific heat of the water and ice remain normal, or the same as they respectively are at the freezing point.

After steam has been formed, a further addition of heat increases the temperature again at a much faster ratio to the quantity of heat added, which ratio also varies according as we maintain a constant pressure or a constant volume ; and I am not aware that any other critical point exists where this will cease to be the fact until we arrive at that very high temperature, known as the point of dissociation, at which it becomes resolved into its original gases.

The heat which has been absorbed by one pound of water to convert it into a pound of steam at atmospheric pressure is sufficient to have melted three pounds of steel or thirteen pounds of gold. This has been transformed into something besides heat ; stored up to reappear as heat when the process is reversed. That condition is what we are pleased to call latent heat, and in it resides mainly the ability of the steam to do work.



The diagram shows graphically the relation of heat to temperature, the horizontal scale being quantity of heat in British thermal units, and the vertical temperature in Fahrenheit degrees, both reckoned from absolute zero and by the usual scale. The dotted lines for ice and water show the temperature which would have been obtained

*See *Scientific American* Supplement, 624, 625, Dec., 1887.

†460° below the zero of Fahrenheit. This is the nearest approximation in whole degrees to the latest determinations of the absolute zero of temperature.

Babcock & Wilcox Boilers fired with Blast Furnace Gas, Bethlehem Steel Works, Bethlehem, Pa. 11,000 H. P. used by this Company.

if the conditions had not changed. The lines marked "gold" and "steel" show the relation to heat and temperature and the melting points of these metals. All the inclined lines would be slightly curved if attention had been paid to the changing specific heat, but the curvature would be small. It is worth noting that, with one or two exceptions, the curves of all substances lie between the vertical and that for water. That is to say, that water has a greater capacity for heat than all other substances except two, hydrogen and bromine.

In order to generate steam, then, only two steps are required: First, procure the heat, and, second, transfer it to the water. Now, you have it laid down as an axiom that when a body has been transferred or transformed from one place or state into another, the same work has been done and the same energy expended, whatever may have been the intermediate steps or conditions, or whatever the apparatus. Therefore, when a given quantity of water at a given temperature has been made into steam at a given temperature, a certain definite work has been done, and a certain amount of energy expended, from whatever the heat may have been obtained, or whatever boiler may have been employed for the purpose.

A pound of coal or any other fuel has a definite heat producing capacity, and is capable of evaporating a definite quantity of water under given conditions. That is the limit beyond which even perfection cannot go, and yet I have known, and doubtless you have heard of, cases where inventors have claimed, and so-called engineers have certified to, much higher results.

The first step in generating steam is in burning the fuel to the best advantage. A pound of carbon will generate 14,500 British thermal units, during combustion into carbonic dioxide, and this will be the same, whatever the temperature or the rapidity at which the combustion may take place. If possible, we might oxidize it at as slow a rate as that with which iron rusts or wood rots in the open air, or we might burn it with the rapidity of gunpowder, a ton in a second, yet the total heat generated would be precisely the same. Again, we may keep the temperature down to the lowest point at which combustion can take place, by bringing large bodies of air in contact with it, or otherwise, or we may supply it with just the right quantity of pure oxygen, and burn it at a temperature approaching that of dissociation, and still the heat units given off will be neither more nor less. It follows, therefore, that great latitude in the manner or rapidity of combustion may be taken without affecting the quantity of heat generated.

But in practice it is found that other considerations limit this latitude, and that there are certain conditions necessary in order to get the most *available* heat from a pound of coal. There are three ways, and only three, in which the heat developed by the combustion of coal in a steam boiler furnace may be expended.

First, and principally, it should be conveyed to the water in the boiler, and be utilized in the production of steam. To be perfect, a boiler should so utilize all the heat of combustion, but there are no perfect boilers.

Second.—A portion of the heat of combustion is conveyed up the chimney in the waste gases. This is in proportion to the weight of the gases, and the difference between their temperature and that of the air and coal before they entered the fire.

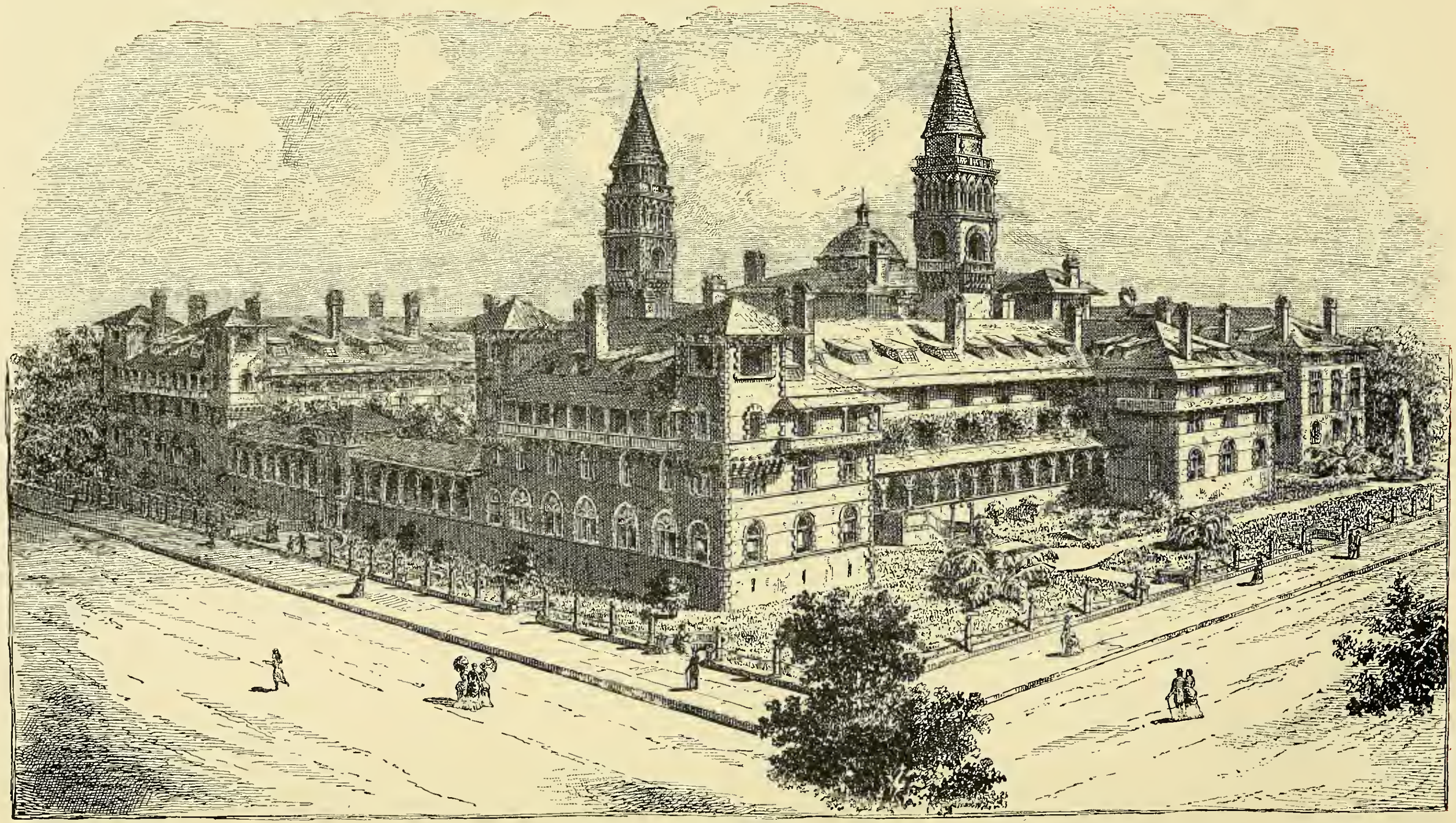
Third.—Another portion is dissipated by radiation from the sides of the furnace. In a *stove* the heat is all used in these latter two ways, either it goes off through the chimney or is radiated into the surrounding space. It is one of the principal problems of boiler engineering to render the amount of heat thus lost as small as possible.

The loss from radiation is in proportion to the amount of surface, its nature, its temperature, and the time it is exposed. This loss can be almost entirely eliminated by thick walls and a smooth white or polished surface, but its amount is ordinarily so small that these extraordinary precautions do not pay in practice.

It is evident that the temperature of the escaping gases cannot be brought below that of the absorbing surfaces, while it may be much greater even to that of the fire. This is supposing that all of the escaping gases have passed through the fire. In case air is allowed to leak into the flues, and mingle with the gases after they have left the heating surfaces, the temperature may be brought down to almost any point above that of the atmosphere, but without any reduction in the amount of heat wasted. It is in this way that those low chimney temperatures are sometimes attained which pass for proof of economy with the unobserving. All surplus air admitted to the fire, or to the gases before they leave the heating surfaces, increases the losses.

We are now prepared to see why and how the temperature and the rapidity of combustion in the boiler furnace affect the economy, and that though the amount of heat developed may be the same, the heat available for the generation of steam may be much less with one rate or temperature of combustion than another.

Assuming that there is no air passing up the



Hotel Ponce de Leon, St. Augustine, Fla. Heat and Power furnished by 416 H.P. of Babcock & Wilcox Boilers.

chimney other than that which has passed through the fire, the higher the temperature of the fire and the lower that of the escaping gases the better the economy, for the losses by the chimney gases will bear the same proportion to the heat generated by the combustion as the temperature of those gases bears to the temperature of the fire. That is to say, if the temperature of the fire is 2,500° and that of the chimney gases 500° above that of the atmosphere, the loss by the chimney will be $\frac{500}{2500} = 20$ per cent. Therefore, as the escaping gases cannot be brought below the temperature of the absorbing surface, which is practically a fixed quantity, the temperature of the fire must be high in order to secure good economy.

The losses by radiation being practically proportioned to the time occupied, the more coal burned in a given furnace in a given time, the less will be the proportionate loss from that cause.

It therefore follows that we should burn our coal rapidly and at a high temperature, to secure the best available economy.

CIRCULATION OF WATER IN STEAM BOILERS.

[From a lecture by George H. Babcock, delivered at Cornell University, February, 1890.]

You have all noticed a kettle of water boiling over the fire, the fluid rising somewhat tumultuously around the edges of the vessel, and tumbling toward the center, where it descends. Similar currents are in action while the water is simply being heated, but they are not perceptible unless there are floating particles in the liquid. These currents are caused by the joint action of the added temperature and two or more qualities which the water possesses.

1. Water, in common with most other substances, expands when heated; a statement, however, strictly true only when referred to a temperature above 39° F. or 4° C., but as in the making of steam we rarely have to do with temperatures so low as that, we may, for our present purposes, ignore that exception.

2. Water is practically a non-conductor of heat, though not entirely so. If ice-cold water was kept boiling at the surface the heat would not penetrate sufficiently to begin melting ice at a depth of three inches in less than about two hours. As, therefore, the heated water cannot impart its heat to its neighboring particles, it remains expanded and rises by its levity, while colder portions come to be heated in turn, thus setting up currents in the fluid.

Now, when all the water has been heated to the boiling point corresponding to the pressure to which it is subjected, each added unit of heat converts a portion, about seven grains in weight, into vapor, greatly increasing its volume; and the mingled steam and water rises more rapidly still, producing ebullition such as we have noticed in the kettle. So long as the quantity of heat added to the contents of the kettle continues practically constant, the conditions remain similar to those we noticed at first, a tumultuous lifting of the water around the edges, flowing toward the center and thence downward; if, however, the fire be quickened, the upward currents interfere with the downward and the kettle boils over. (Fig. 1.)

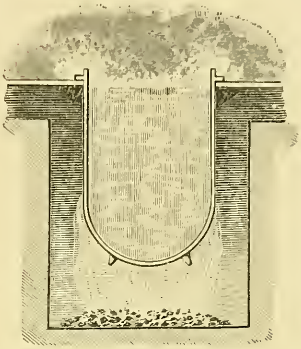


Fig. 1.

If now we put in the kettle a vessel somewhat smaller (Fig. 2) with a hole in the bottom and supported at a proper distance from the side so as to separate the upward from the downward currents, we can force the fires to a very much greater extent without causing the kettle to boil over, and when we place a deflecting plate so as to guide the rising column toward the center it will be almost impossible to produce that effect. This is the invention of Perkins in 1831 and forms the basis of very many of the arrangements for producing free circulation of the water in boilers which have been made since that time. It consists in dividing the currents so that they will not interfere each with the other.

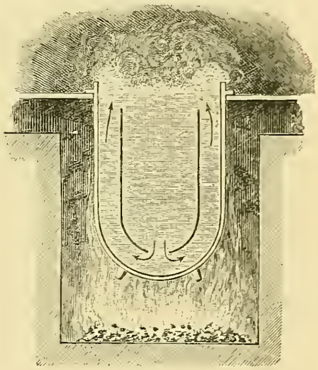
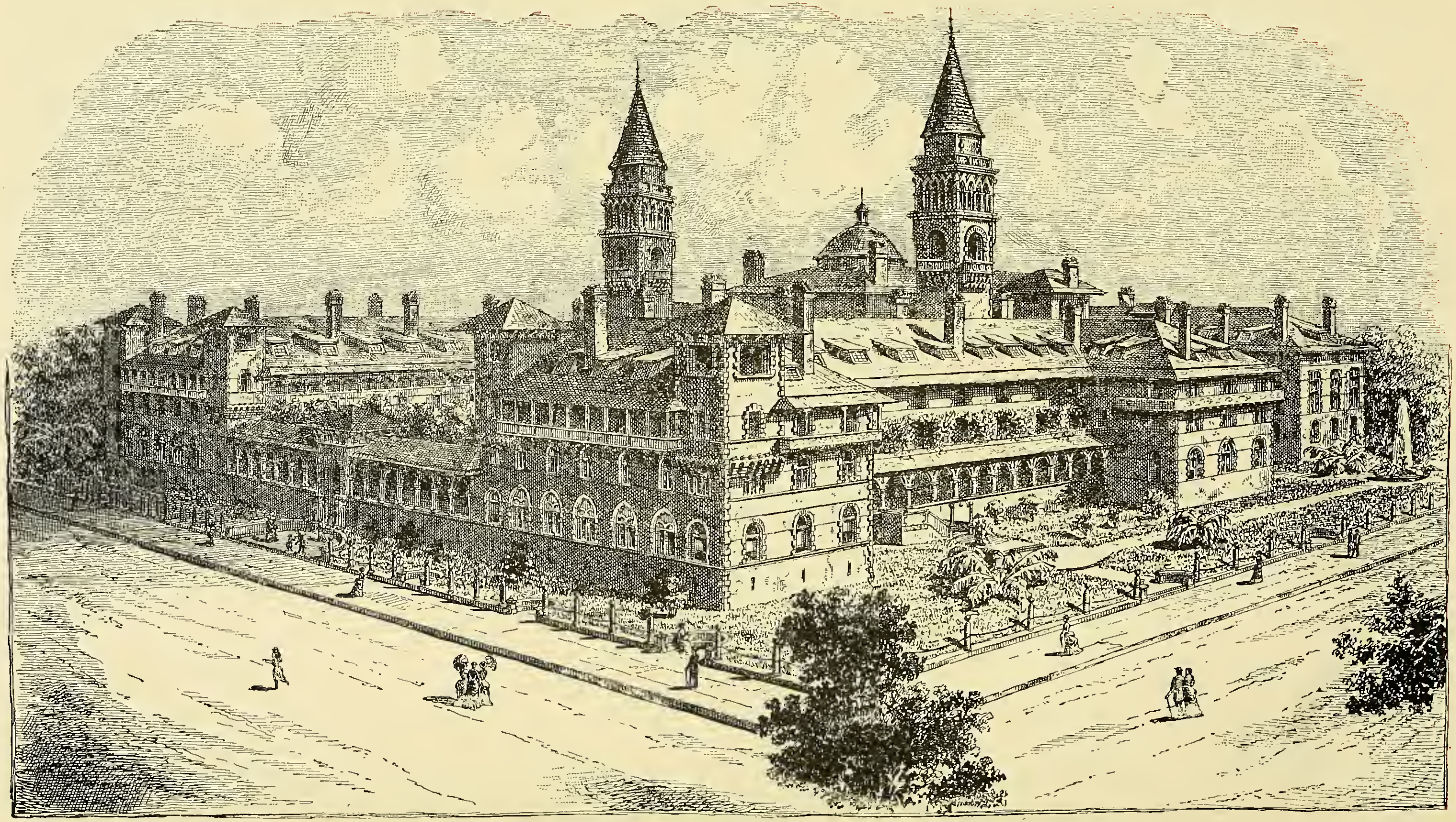


Fig. 2.

But what is the object of facilitating the circulation of water in boilers? Why may we not safely leave this to the unassisted action of nature as we do in culinary operations? We may, if we do not care for the three most important aims in steam-boiler construction, namely, efficiency, durability, and safety, each of which is more or less dependent upon a proper circulation of the water. As for efficiency, we have seen one proof in our kettle. When we provided means to preserve the circulation, we found that



Hotel Ponce de Leon, St. Augustine, Fla. Heat and Power furnished by 416 H.P. of Babcock & Wilcox Boilers.

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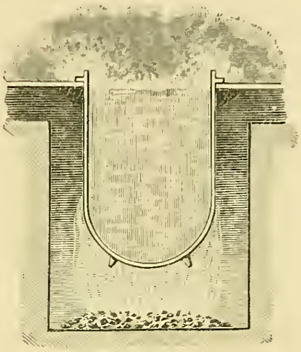

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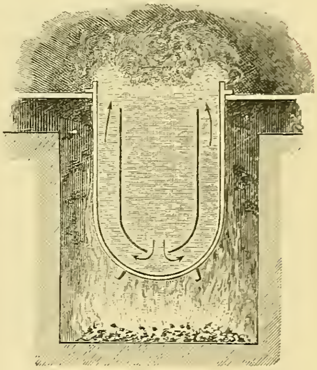

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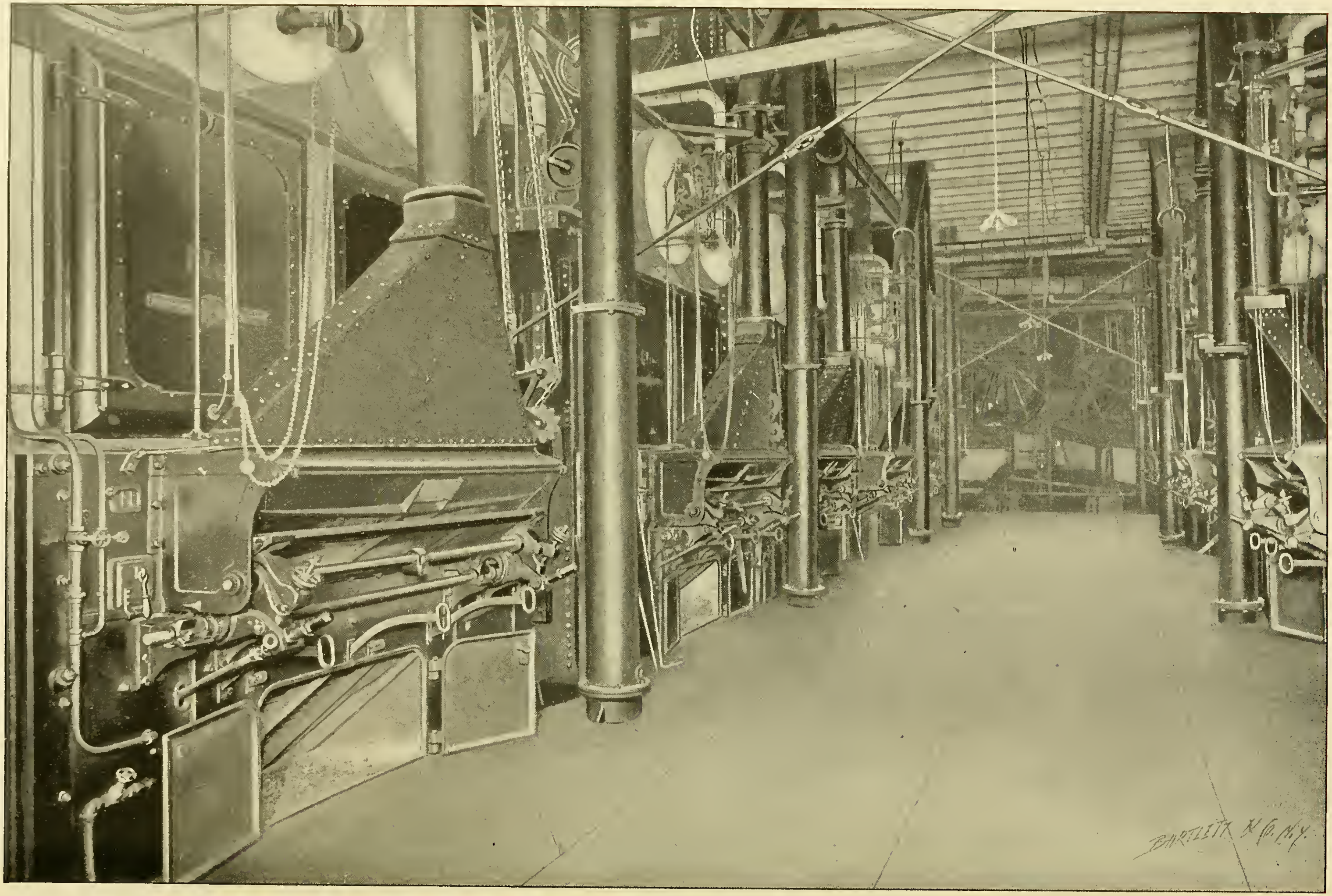


Babcock & Wilcox Boilers fitted with Roney Stokers, in 96th Street Station, Metropolitan Street Railway Co., N. Y. 60,000 H. P. in the various stations of this Company and its leased lines.

we could carry a hotter fire and boil away the water much more rapidly than before. It is the same in a steam boiler. And we also noticed that when there was nothing but the unassisted circulation, the rising steam carried away so much water in the form of foam that the kettle boiled over, but when the currents were separated and an unimpeded circuit was established, this ceased, and a much larger supply of steam was delivered in a comparatively dry state. Thus, circulation increases the efficiency in two ways: it adds to the ability to take up the heat, and decreases the liability to waste that heat by what is technically known as priming. There is yet another way in which, incidentally, circulation increases efficiency of surface, and that is by preventing in a greater or less degree the formation of deposits thereon. Most waters contain some impurity which, when the water is evaporated, remains to incrust the surface of the vessel. This incrustation becomes very serious sometimes, so much so as to almost entirely prevent the transmission of heat from the metal to the water. It is said that an incrustation of only ⅛ inch will cause a loss of 25 per cent. in efficiency, and that is probably within the truth in many cases. Circulation of water will not prevent incrustation altogether, but it lessens the amount in all waters, and almost entirely so in some, thus adding greatly to the efficiency of the surface.

A second advantage to be obtained through circulation is *durability* of the boiler. This it secures mainly by keeping all parts at a nearly uniform temperature. The way to secure the greatest freedom from unequal strains in a boiler is to provide for such a circulation of the water as will insure the same temperature in all parts.

3. *Safety* follows in the wake of durability, because a boiler which is not subject to unequal strains of expansion and contraction is not only less liable to ordinary repairs, but also to rupture and disastrous explosion. By far the most prolific cause of explosions is this same strain from unequal expansions.

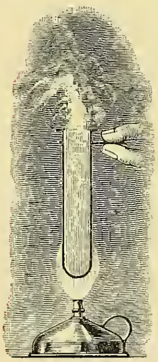


Fig. 3.

Having thus briefly looked at the advantages of circulation of water in steam boilers, let us see what are the best means of securing it under the most efficient conditions. We have seen in our kettle that one essential point was that the currents should be kept from interfering with each other. If we could look into an ordinary return tubular boiler when steaming, we should see a curious commotion of currents rushing hither and thither, and shifting continually as one or the other contending force gained a momentary mastery. The principal upward currents would be found at the two ends, one over the fire and the other over the first foot or so of the tubes. Between these, the downward currents struggle against the rising currents of steam and water. At a sudden demand for steam, or on the lifting of the safety valve, the pressure being slightly reduced, the water jumps up in jets at every portion of the surface, being lifted by the sudden generation of steam throughout the body of water. You have seen the effect of this sudden generation of steam in the well-known experiment with a Florence flask, to which a cold application is made while boiling water under pressure is within. You have also witnessed the geyser-like action when water is boiled in a test tube held vertically over a lamp (Fig. 3).

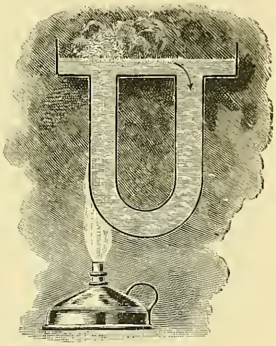


Fig. 4.

If now we take a U tube depending from a vessel of water (Fig. 4) and apply the lamp to one leg a circulation is at once set up within it, and no such spasmodic action can be produced. This U tube is the representative of the true method of circulation within a water tube boiler properly constructed. We can, for the purpose of securing more heating surface, extend the heated leg into a long incline (Fig. 5), when we have the well-known inclined-tube generator. Now, by adding other tubes, we may further increase the heating surface (Fig. 6), while it will still be the U tube in effect and action. In such a construction the circulation is a function of the difference in density of the two columns. Its velocity is measured by the well-known Torricellian formula, $V = \sqrt{2gh}$, or, approximately, $V = 8\sqrt{h}$, h being measured in terms of the lighter fluid. This velocity will increase until the rising column becomes all steam, but the *quantity* or weight circulated will attain a maximum when the density of the mingled steam and water in the rising column becomes one-half that of the solid water in the descending column,

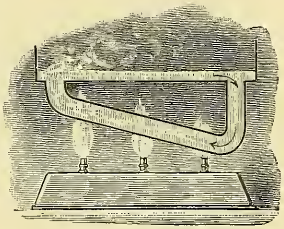
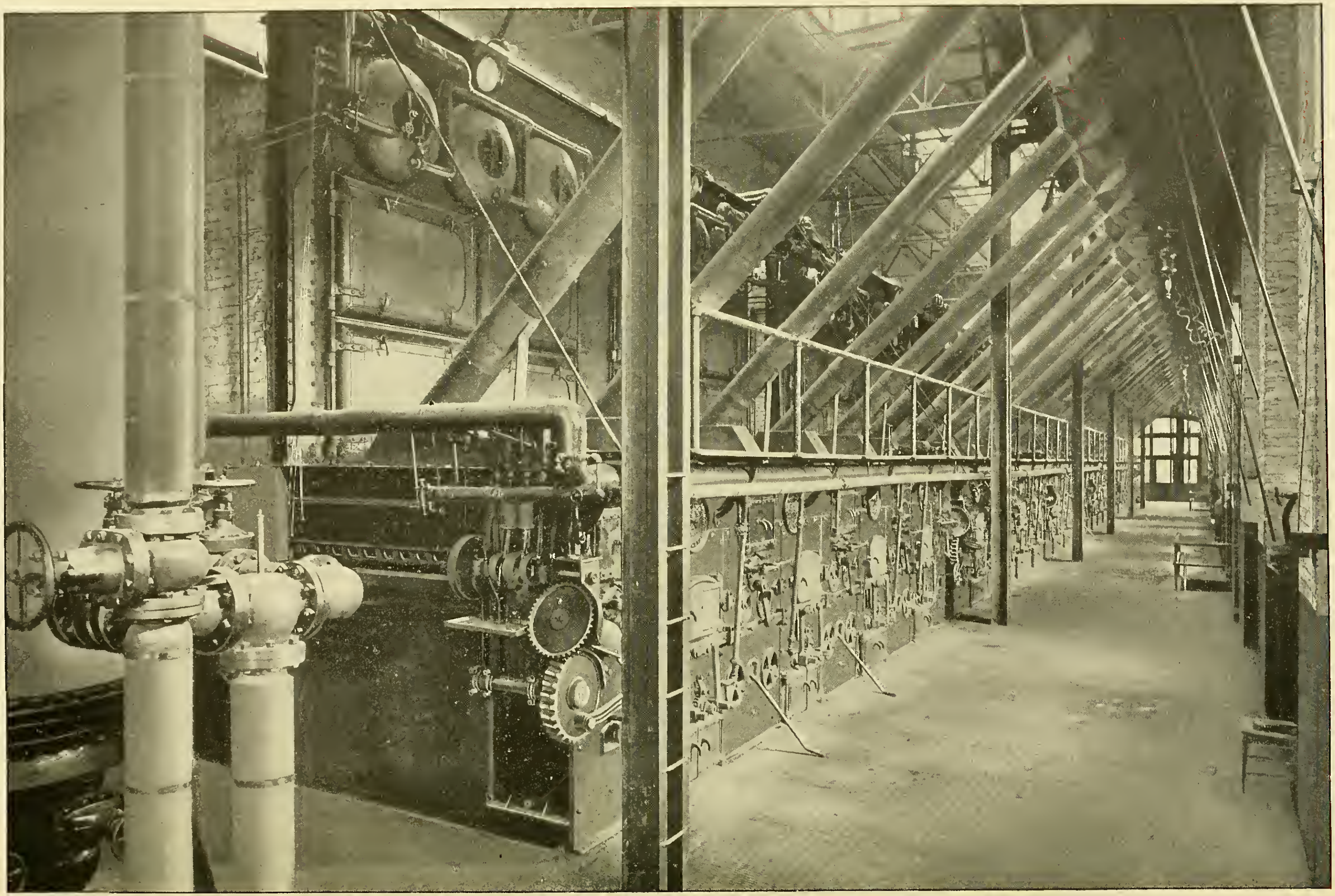


Fig. 5.



Northwestern Elevated R. R. Co., Chicago, Ill. 4800 H. P. Babcock & Wilcox Boilers fitted with Murphy Furnaces.

which is nearly coincident with the condition of half steam and half water, the weight of the steam being very slight compared to that of the water.

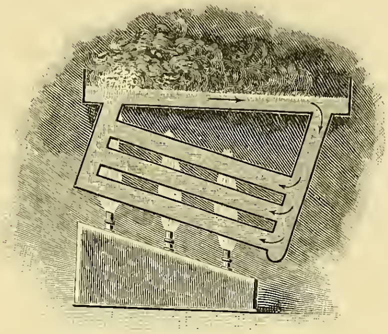


Fig. 6.

It becomes easy by this rule to determine the circulation in any given boiler built on this principle, provided the construction is such as to permit a free flow of the water. Of course, every bend detracts a little and something is lost in getting up the velocity, but when the boiler is well arranged and proportioned these retardations are slight.

Let us take for example one of the 240-horse power Babcock & Wilcox boilers here in the University. The height of the columns may be taken as four and one-half feet, measuring from the surface of the water to about the center of the bundle of tubes over the fire, and the head would be equal to this height at the maximum of circulation. We should, therefore, have a velocity of $8\sqrt{4\frac{1}{2}} = 16.97$, say 17 feet per second. There are in this boiler fourteen sections, each having a 4″ tube opening into the drum, the area of which (inside) is 11 square inches, the 14 aggregating 154 square inches, or 1.07 square feet. This multiplied by the velocity, 16.97 feet, gives 18.16 cubic feet mingled steam and water discharged per second, one half of which, or 9.08 cubic feet, is steam. Assuming this steam to be at 100 pounds gauge pressure, it will weigh 0.258 pound per cubic foot. Hence, 2.34 pounds of steam will be discharged per second, and 8,433 pounds per hour. Dividing this by 30, the number of pounds representing a boiler horse power, we get 281.1 horse power, about 17 per cent. in excess of the rated power of the boiler. The water at the temperature of steam at 100 pounds pressure weighs 56 pounds per cubic foot, and the steam 0.258 pound, so that the steam forms but $\frac{1}{218}$ part of the mixture by weight, and consequently each particle of water will make 218 circuits before being evaporated when working at this capacity, and circulating the maximum weight of water through the tubes.

It is evident that at the highest possible velocity of exit from the generating tubes, nothing but steam will be delivered and there will be no circulation of water except to supply the place of that evaporated. Let us see at what rate of steaming this would occur with the boiler under consideration. We shall have a column of steam, say four feet high on one side and an equal column of water on the other. Assuming, as before, the steam at 100 pounds and the water at same temperature, we will have a head of 866 feet of *steam* and an issuing velocity of 235.5 feet per second. This multiplied by 1.07 square feet of opening and 3,600 seconds in an hour gives 234,043 pounds of steam, which, though only one-eighth the *weight* of mingled steam and water delivered at the maximum, gives us 7,801 horse power, or *over 32 times* the rated power of the boiler. Of course, this is far beyond any possibility of attainment, so that it may be set down as certain that this boiler cannot be forced to a point where there will not be an efficient circulation of the water. By the same method of calculation it may be shown that when forced to double its rated power, a point rarely expected to be reached in practice, about two-thirds the volume of mixture of steam and water delivered into the drum will be steam, and that the water will make 110 circuits while being evaporated. Also that when worked at only about one-quarter its rated capacity, one-fifth of the volume will be steam and the water will make the rounds 870 times before it becomes steam. You will thus see that in the proportions adopted in this boiler there is provision for perfect circulation under all the possible conditions of practice.

In designing boilers of this style it is necessary to guard against having the uptake at the upper end of the tubes too large, for if sufficiently large to allow downward currents therein, the whole effect of the rising column in increasing the circulation in the tubes is nullified (Fig. 7). This will readily be seen if we consider the uptake very large—when the only head producing circulation in the tubes will be that due to the inclination of each tube taken by itself. This objection is only overcome when the uptake is so small as to

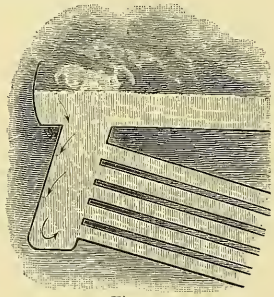
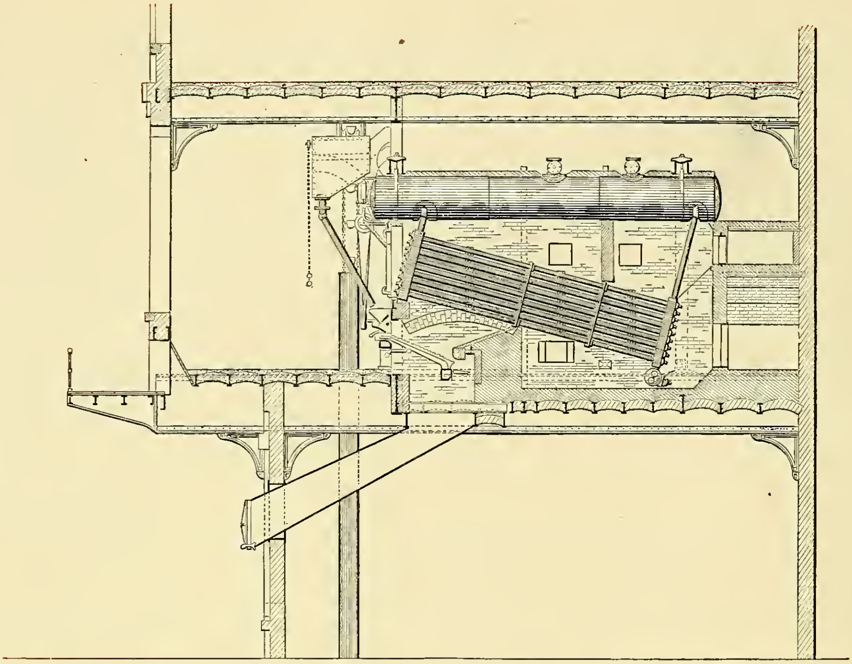
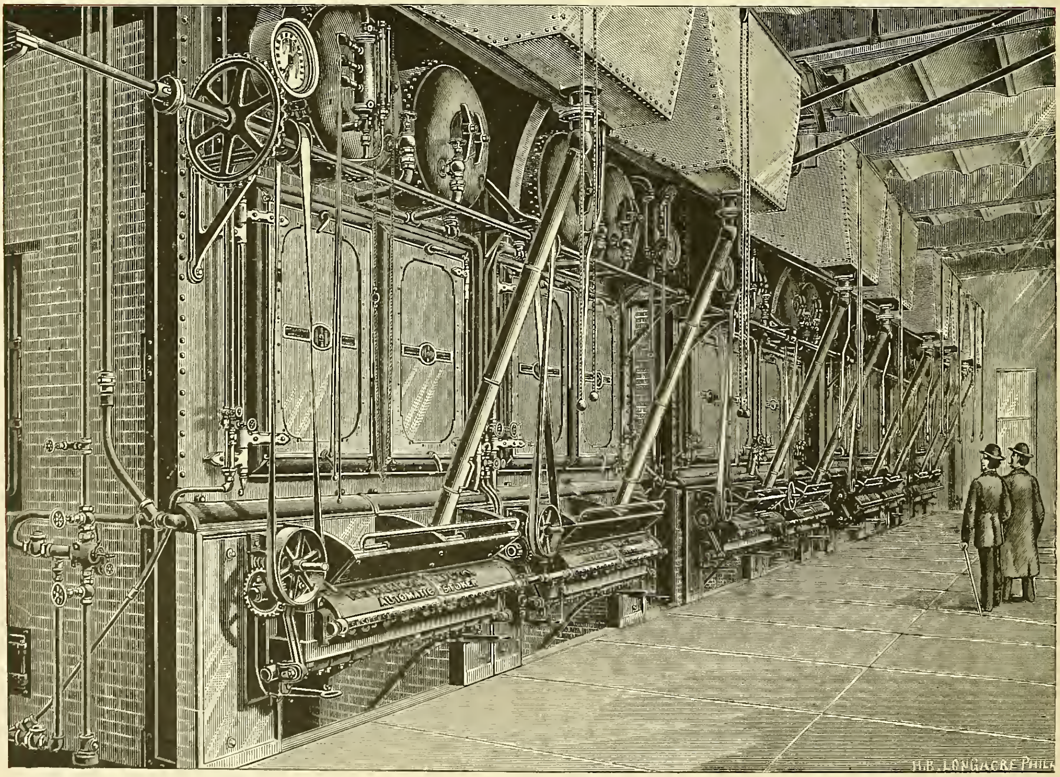


Fig. 7.





Babcock & Wilcox Boilers at Baldwin Locomotive Works, Philadelphia, Pa. 3464 H.P. now in use.

be entirely filled with the ascending current of mingled steam and water. It is also necessary that this uptake should be practically direct, and it should not be composed of frequent enlargements and contractions. Take, for instance, a boiler well known in Europe, copied and sold here under another name. It is made up of inclined tubes secured by pairs into boxes at the ends, which boxes are made to communicate with each other by return bends opposite the ends of the tubes. These boxes and return bends form an irregular uptake, whereby the steam is expected to rise to a reservoir above. You will notice (Fig. 8) that the upward current

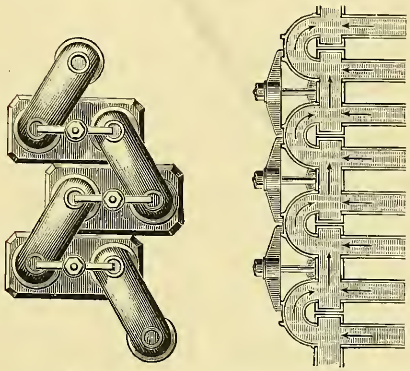


Fig. 8. [Developed to show Circulation.]

of steam and water in the return bend meets and directly antagonizes the upward current in the adjoining tube. Only one result can follow. If their velocities are equal, the momentum of both will be neutralized and all circulation stopped, or, if one be stronger, it will cause a back flow in the other by the amount of difference in force, with practically the same result.

In a well known boiler, many of which were sold, but of which none are now made and very few are still in use, the inventor claimed that the return bends and small openings against the tubes were for the purpose of "restricting the circulation," and no doubt they performed well that office; but excepting for the smallness of the openings they were not as efficient for that purpose as the arrangement shown in Fig. 8.

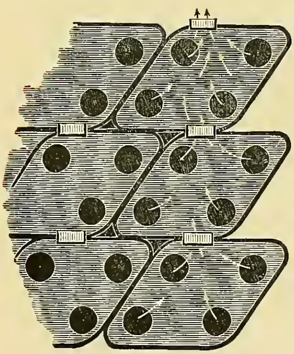


Fig. 9.

Another form of boiler, first invented by Clarke or Crawford, and lately revived, has the uptake made of boxes into which a number, generally from two to four, tubes are expanded, the boxes being connected together by nipples (Fig. 9). It is a well-known fact that where a fluid flows through a conduit which enlarges and then contracts, the velocity is lost to a greater or less extent at the enlargements, and has to be gotten up again at the contractions each time, with a corresponding loss of head. The same thing occurs in the construction shown in Fig. 9. The enlargements and contractions quite destroy the head and practically overcome the tendency of the water to circulate.

A horizontal tube stopped at one end, as shown in Fig. 10, can have no proper circulation within it. If moderately driven, the water may struggle in against the issuing steam sufficiently to keep the surfaces covered, but a slight degree of forcing will cause it to act like the test tube in Fig. 3, and the more there are of them in a given boiler the more spasmodic will be its working.

The experiment with our kettle (Fig. 2) gives the clue to the best means of promoting circulation in ordinary shell boilers. Steenstrup or "Martin" and "Galloway" water tubes placed in such boilers also assist in directing the circulation therein, but it is almost impossible to produce in shell boilers, by any means, the circulation of all the water in one continuous round, such as marks the well-constructed water-tube boiler.

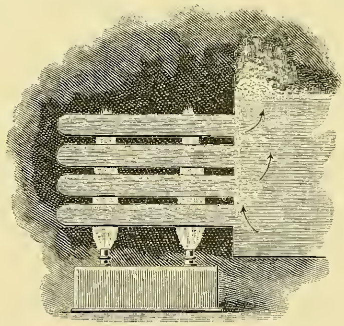
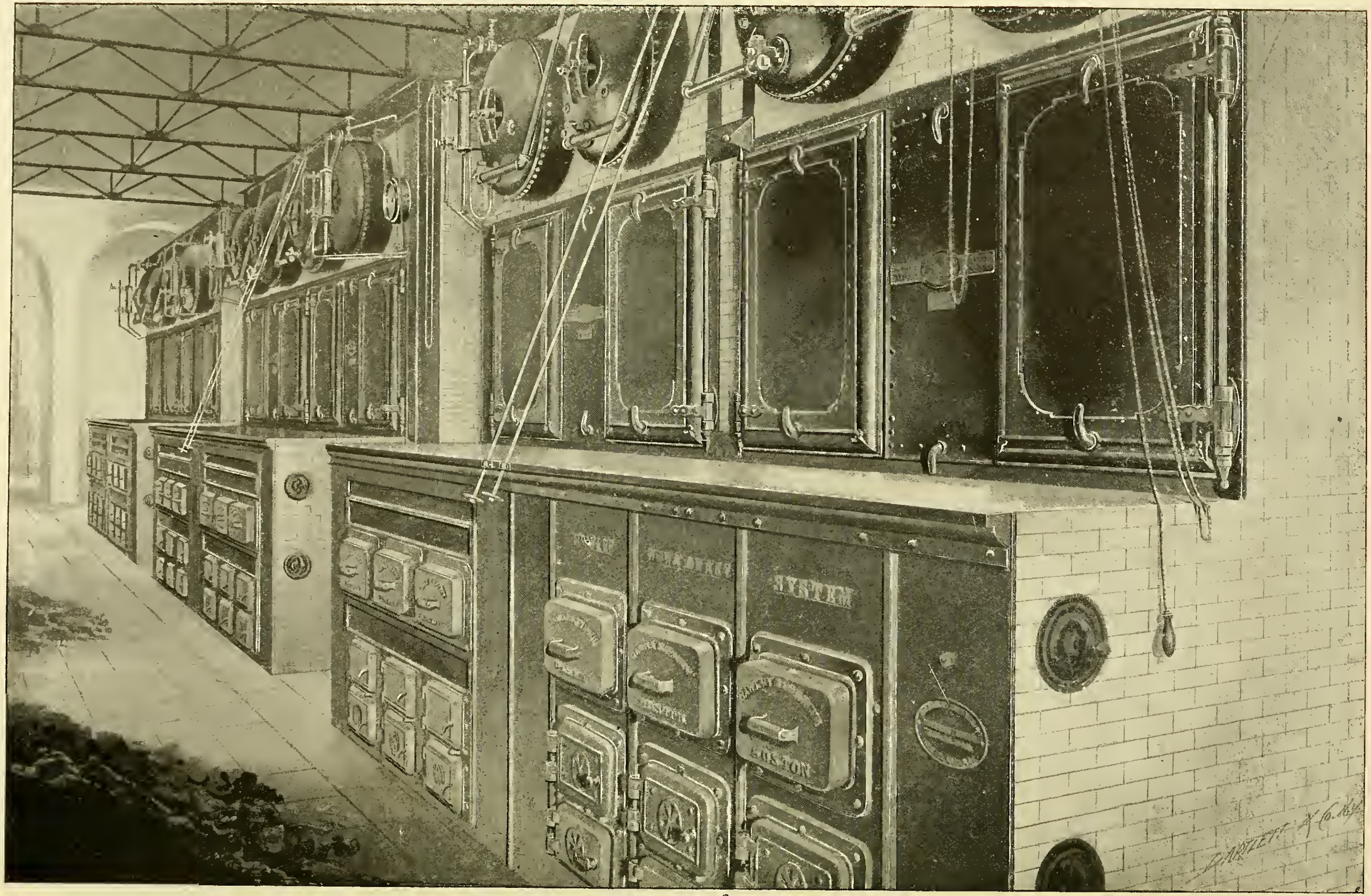


Fig. 10.

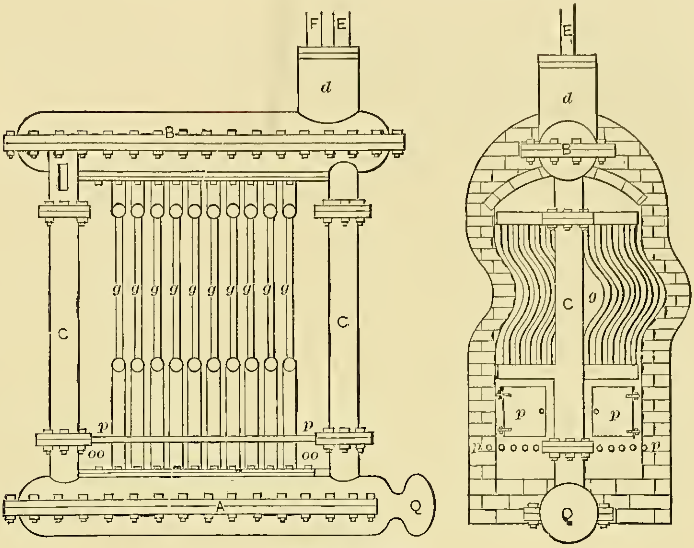
As I have before remarked, provision for a proper circulation of water has been almost universally ignored in designing steam boilers, sometimes to the great damage of the owner, but oftener to the jeopardy of the lives of those who are employed to run them. The noted case of the Montana and her sister ship, where some $300,000 was thrown away in trying an experiment which a proper consideration of this subject would have avoided, is a case in point; but who shall count the cost of life and treasure not, perhaps, directly traceable to, but, nevertheless, due entirely to such neglect in design and construction of the thousands of boilers in which this necessary element has been ignored?



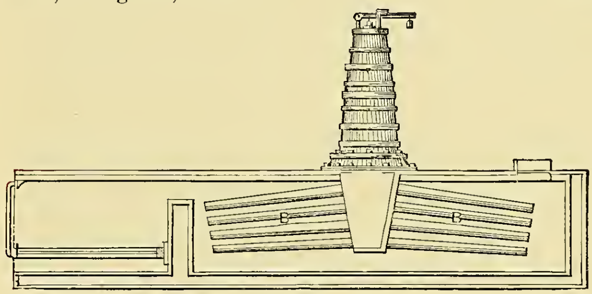
Merrimack Manufacturing Company, Lowell, Mass. 1925 H. P. Babcock & Wilcox Boilers fitted with Hawley Down-Draft Furnaces.

*BRIEF HISTORY OF WATER-TUBE BOILERS.**

Water-tube boilers are not new. From the earliest days of the steam engine, there have been those who recognized their advantages. The first water-tube boiler recorded was made by a contemporary of Watt, William Blakey, in 1766. He arranged several tubes in a furnace, alternately inclined at opposite angles, and connected at their contiguous ends by smaller pipes. But the first successful user of such boilers was James Rumsay, an American inventor, celebrated for his early experiments in steam navigation, and who may be truly classed as the originator of the water-tube boiler, as now known. In 1788 he patented, in England, several



Joseph Eve, 1825.



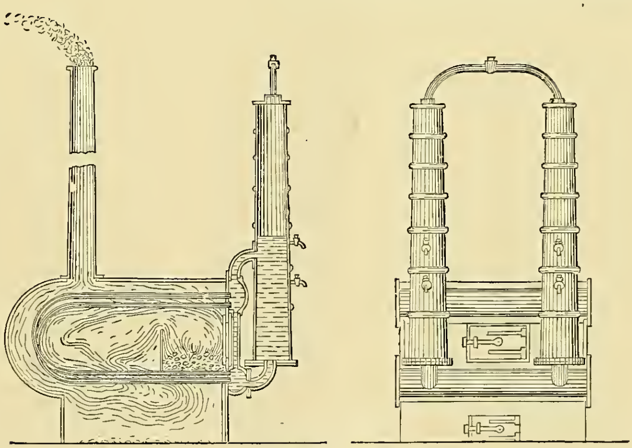
Stevens, 1805.

forms of boilers, among them, one having a fire-box with flat water-sides and top, across which were horizontal water-tubes connecting with the water spaces. Another was a coiled tube within a cylindrical fire-box, connecting at its two ends with the annular surrounding water space. This was the first of the "coil boilers." Another form in the same patent was the vertical tubular boiler, as at present made.

The first boiler made of a combination of small tubes, connected at one end to a reservoir, was the invention of another American, John Cox Stevens, in 1805.

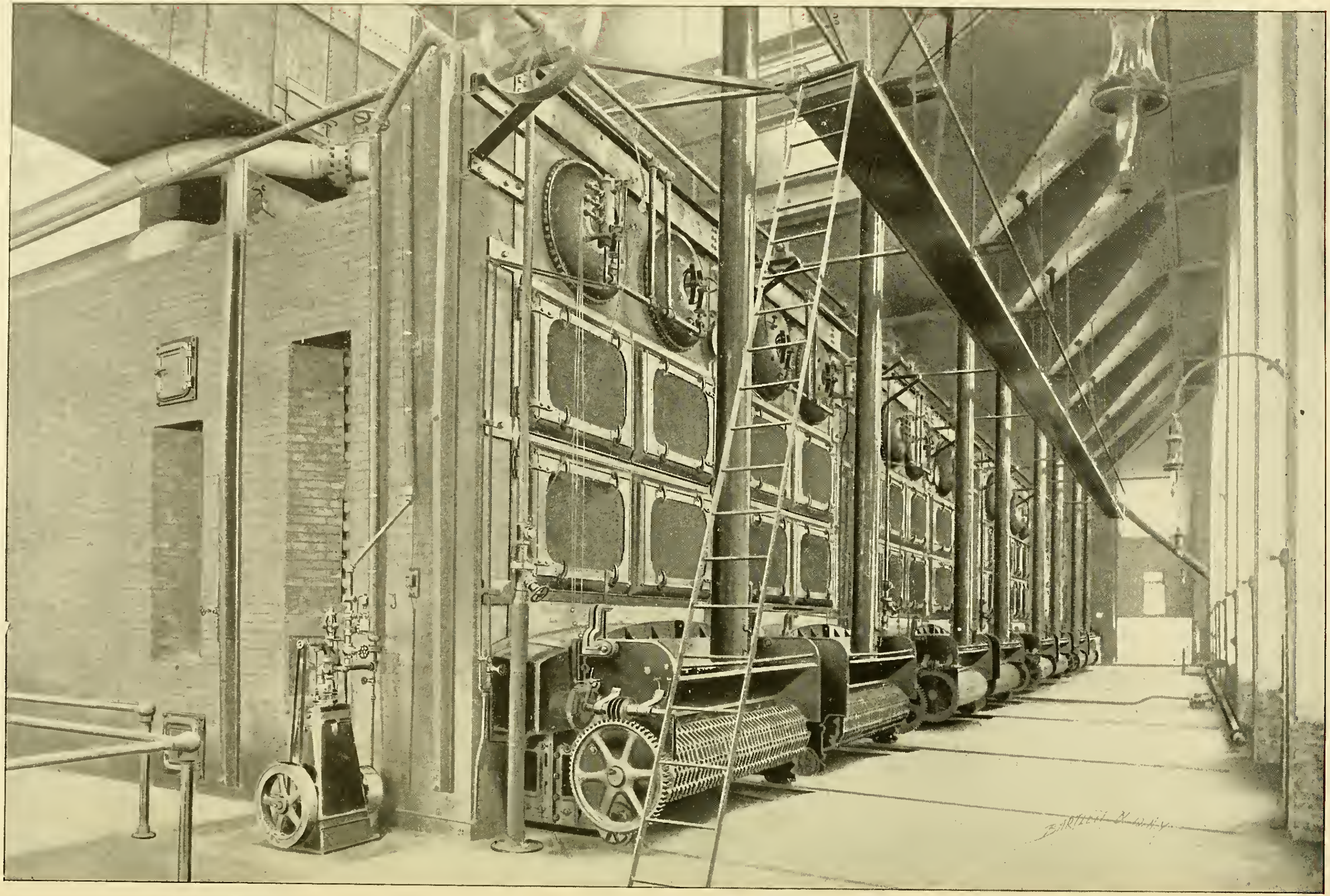
This boiler was actually employed to drive a steamboat on the Hudson River, but like all the "porcupine" boilers of which it was the first, it did not have the elements of a continued success.

About the same time, Wolf, the inventor of compound engines, made a boiler of large horizontal tubes, laid across the furnace and connected at the ends to a longitudinal drum above. The first purely sectional water-tube boiler



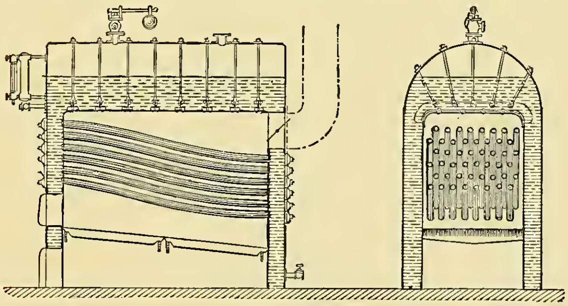
Gurney, 1826.

* See discussion by Geo. H. Babcock, of Sterling's paper on "Water-tube and Shell Boilers," in *Trans. Am. Society of Mechanical Engineers*, Vol. VI., p. 601.



4800 H. P. Babcock & Wilcox Boilers with Babcock & Wilcox Chain Grate Stokers. South Side Elevated R. R. Co., Chicago, Ill.

was made by Julius Griffith, in 1821, who used a number of horizontal water-tubes connected to vertical side pipes, which were in turn connected to horizontal gathering pipes, and these to a steam drum. The first sectional water-tube boiler, with a well-defined circulation, was made by Joseph Eve, in 1825. His sections were composed of small tubes slightly double curved but practically vertical, fixed in horizontal headers, which were in turn connected to a steam space above and water space below formed of larger pipes, and connected by outside pipes so as to secure a circulation of the water up through the sections and down the external pipes. The same year John M'Curdy, of New York, made a "Duplex Steam Generator," of "tubes of wrought or cast-iron or other material" arranged in several horizontal rows, connected together alternately front and rear by return bends. In 1826, Goldsworthy Gurney made a number of boilers which he used on his steam carriages, consisting of a series of small tubes bent into the shape of a U laid edgewise, which connected top and bottom with large horizontal pipes. These latter were united by

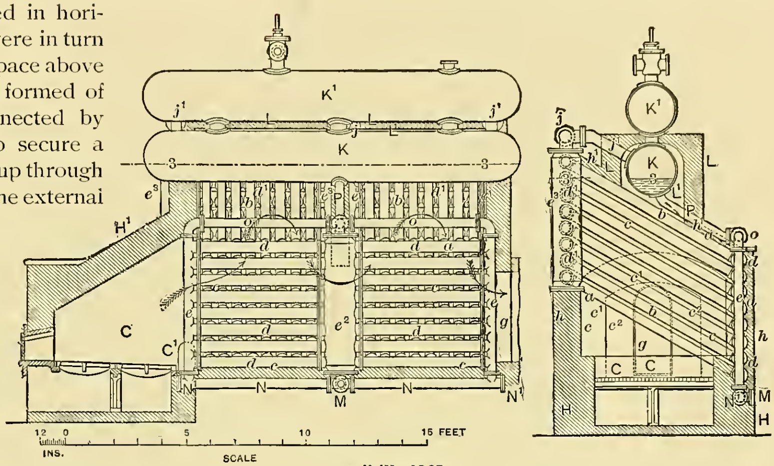


Wilcox, 1856.

vertical pipes to permit of circulation, and also connected to a vertical cylinder forming the steam and water reservoirs. In 1828, Paul Steenstrup made the first shell boiler with vertical water-tubes in the large flues, similar to what is known as the "Martin," and suggesting the "Galloway."

The first water-tube boiler having fire-tubes within water-tubes was made in 1830, by Summers & Ogle. Horizontal connections at top and bottom had a series of vertical water-tubes connecting them, through which were fire-tubes extending through the horizontal connections, with nuts upon them to bind the parts together and make the joints, suggesting some recent patents.

The first person to use *inclined* water-tubes connecting water spaces front and rear with a steam space above, was Stephen Wilcox in 1856, and the first to make such inclined tubes into a

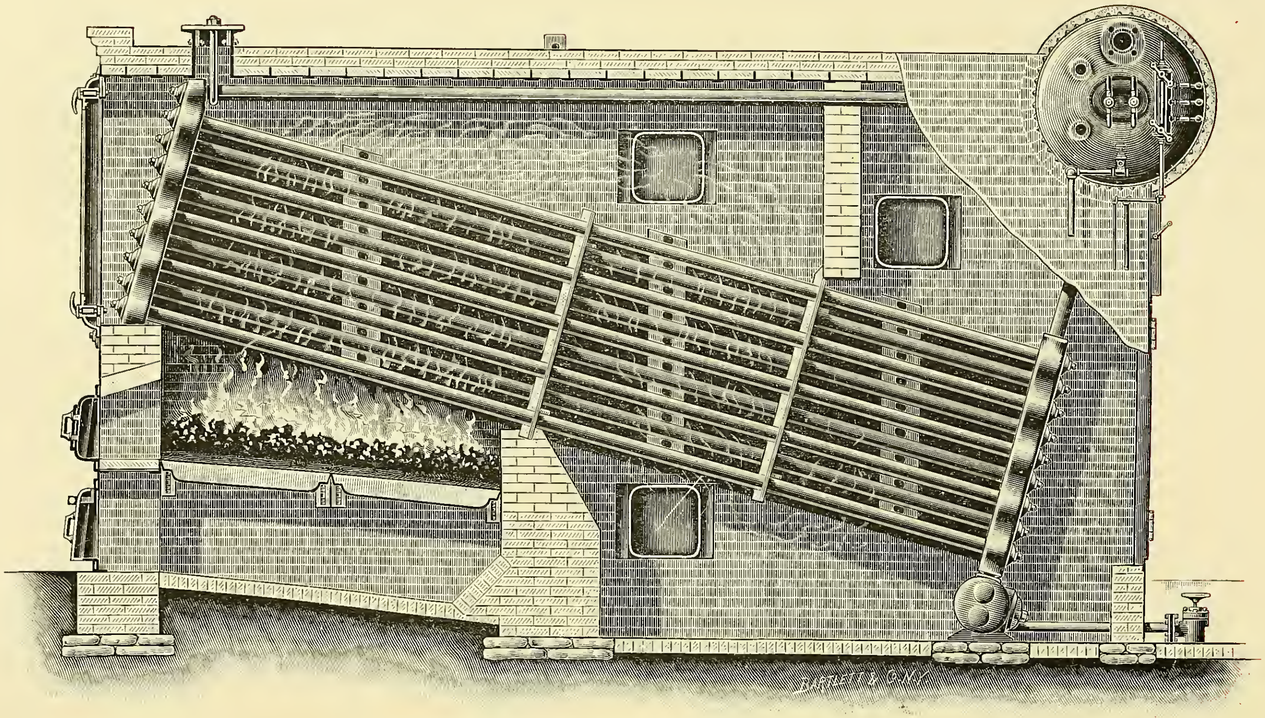


Twibill, 1865.

sectional form was one Twibill in 1865. He used wrought-iron tubes connected front and rear by intermediate connections with stand pipes, which carried the steam to a horizontal cross-drum at the top, the entrained water being carried back to the rear.

Time would fail to tell of Clark, and Perkins, and Moore (English), and McDowell, and Alban, and Craddock, and the host of others who have tried to make water-tube boilers, and have not made practical successes, because of the difficulties of the problem.

Why are not water-tube boilers in more general use, compared with shell boilers? is asked. Because they require a high class of engineering to make them successful. The plain cylinder is an easy thing to make. It requires little skill to rivet sheets into a cylinder, build a fire under it and call it a boiler; and because it is easy and anyone can make such a boiler—because it requires no special engineering—they have been made, and are still made, to a very large extent. The water-tube boiler, on the other hand, requires much more skill in order to make it successful. This is proved by the great number of failures in attempts to make water-tube boilers, some of which are referred to in the paper under discussion.



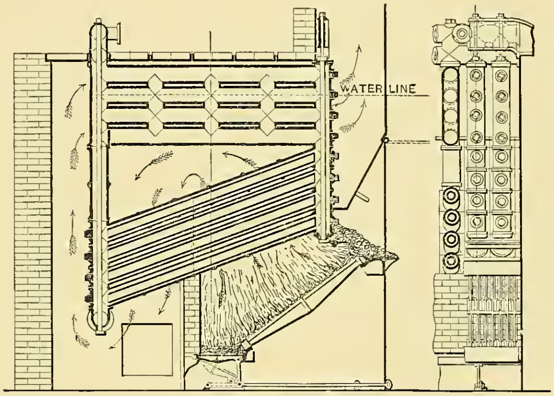
Side View of Cross Drum Type Babcock & Wilcox Boiler.

EVOLUTION OF THE BABCOCK & WILCOX WATER-TUBE BOILER.

We learn quite as much from the record of failures as through the results of success. When a thing has been once fairly tried and found to be impracticable, or imperfect, the knowledge of that trial forms a beacon light to warn those who come after not to run upon the same rock. Still it is an almost everyday occurrence that a device or construction which has been tried and found wanting if not worthless, is again brought up as a great improvement upon other things which have proved by their survival to have been the "fittest." This is particularly the case when a person or firm have, by long and expensive experience, succeeded in supplying a felt want, and developed a business which promises to pay them in the end for their trouble and outlay; immediately a class of persons, who desire to reap where they have not sown, rush into the market with something similar, and, generally, with some idea which the successful party had tried and discarded, claiming it as an "improvement," seek to entice customers, who in the end find they have spent their money for that which satisfieth not. And not infrequently steam users, having been inadvertently induced to experiment on the ill-digested plans of some unfledged inventor, unjustly condemn the whole class, and resolve henceforth to stick to the things their fathers approved.

The success of the Babcock & Wilcox boiler is due to many years constant adherence to one line of research, experimenting and practical working. In that time they have tried many plans which have not proved to be practicable, and were in fact, in whole or in part, failures. During this time they have seen *more than thirty* water-tube or sectional boilers put upon the market, by other parties, some of which attained to some distinction and sale, but all of which have completely disappeared, leaving scarce a trace behind, save in the memories of their victims. The following list—not complete—will serve to bring the names of some to memories which can recall twenty years or less: Dimpfel, Howard, Griffith & Wundrum, Dinsmore, Miller "Fire-box," Miller "American," Miller "Internal Tube," Miller "Inclined Tube," Phleger, Weigand, the Lady Verner, the Allen, the Kelly, the Anderson, the Rogers & Black, the Eclipse or Kilgore; the Moore, the Baker & Smith, the Renshaw, the Shackleton, the "Duplex," the Pond & Bradford, the Whittingham, the Bee, the Hazleton or "Common Sense," the Reynolds, the Suplee or Luder, the Babbitt, the Reed, the Smith, the Standard, &c.

It is with the object of protecting our customers and friends from disappointment and loss through purchasing such discarded ideas, that we publish the following illustrations of experiments made by us in the development of our present boiler, the value and success of which is evidenced by the fact that the largest and most discriminate buyers continue to purchase them after years of practical experience with their workings.



No. 1.

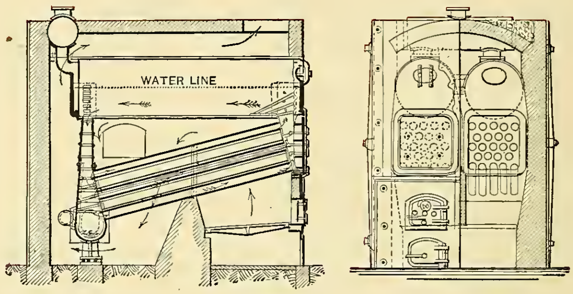
No. 1.—The original Babcock & Wilcox boiler, patented in 1867. The main idea was safety; to it all other elements were sacrificed wherever they conflicted. The boiler consisted of a nest of horizontal tubes serving as steam and water reservoir, placed above and connected at each end by bolted joints, to a nest of inclined heating tubes filled with water. Internal tubes were placed in these latter to assist circulation. The tubes were placed in vertical rows above each other, each vertical row and its connecting end forming a single casting. Hand holes were placed at the end of each tube for cleaning.

No. 2.—The internal circulation tubes were found to hinder, rather than help, circulation and were left out.

Nos. 1 and 2 were found to be faulty in both material and design, cast metal proving itself unfit for heating surfaces placed directly over the fire, cracking as soon as they became coated with scale.

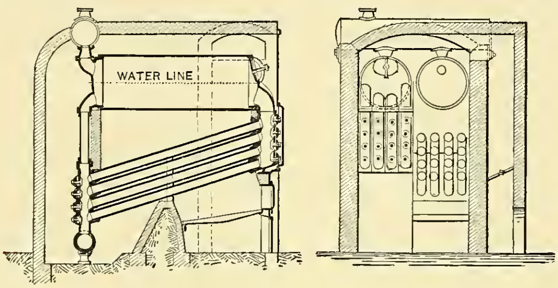
No. 3.—Wrought-iron tubes were substituted for the cast-iron heating tubes, the ends being brightened and laid in the mould, the headers cast on.

The steam and water capacity was insufficient to secure regularity of action, having no reserve to draw upon when irregularly fed or fired. The attempt to dry the wet steam, produced by superheating in the nest of tubes which formed the steam space, was found to be impracticable; the steam delivered was either wet, dry, or superheated, according to the demands upon the boiler. Sediment was found to lodge in the lowest point of the boiler at the rear end, and the exposed portion of the castings cracked off when subjected to the furnace heat.



No. 5.

No. 4.—A plain cylinder carrying the water line at the center, leaving the upper half for

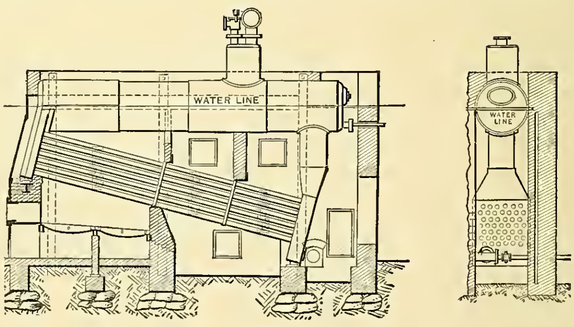


No. 4.

steam space, was substituted for the nest of tubes. The sections were made as in No. 3, and a mud-drum added to the rear end of the sections at the lowest point farthest removed from the fire; the gases passed off to the stack at one side without coming in contact with it. Dry steam was secured by the great increase of separating surface and steam space, and the added water capacity furnished a storage for heat to tide over the irregularities of feeding and firing. By the addition of the drum it lost a little in *safety*, but, on the other hand, it became a serviceable and practical design, retaining all the elements of safety except small diameter of steam reservoir, which was never large, and was removed from the direct action of the fire, but difficulties were encountered in securing reliable joints between the wrought-iron tubes and the cast-iron headers.

No. 5.—Wrought-iron water legs were substituted for the cast-iron headers; the tubes were expanded into the inside sheets, and a large cover placed opposite the front end of the tubes for cleaning. The staggered position of tubes, one above the other, was introduced and found to be more efficient and economical than where the tubes were placed in vertical rows. In other respects it was similar to No. 4, but it had further lost the important element of safety, the sectional construction, and a very objectionable feature, that of flat stayed surfaces, had been introduced. The large doors for access to the tubes were also a cause of weakness. A large plant of these boilers was placed in the Calvert Sugar Refinery, Baltimore, and did good work, but they were never duplicated.

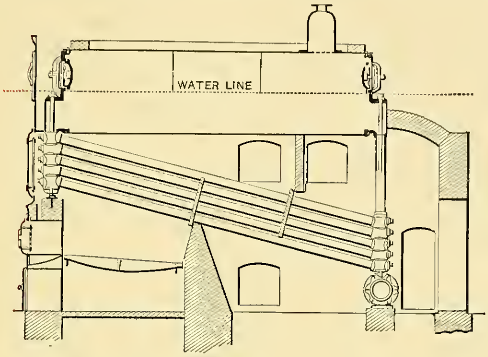
No. 6.—A modification of No. 5, in which longer tubes were used, with three passages of the gases across them, to obtain better economy. Also some of the stayed surfaces were omitted and hand holes were substituted for the large doors. A number of this type were built, but their excessive first cost, lack of adjustability of the structure under varying temperatures, and the inconvenience of transporting the last two styles together with the difficulty of erecting large plants without enormous cost for brickwork, as well as the "commercial engineering" of several competing



No. 6.

firms then in the market, who made a selling point of their ability to add power to any given boiler after it had once been erected, led to:—

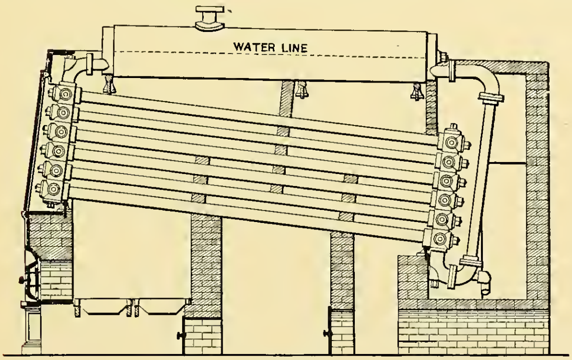
No. 7.—In this, separate T heads were screwed on to the end of each inclined tube; their faces milled off, the tubes placed on top of each other, metal to metal, and bolted together by long bolts



No. 7.

passed through each vertical section of tube heads, and the connecting boxes on the heads of the drum. A large number of these boilers were put into use, some of which are still at work after sixteen to twenty years, but most of them have been altered to the later type.

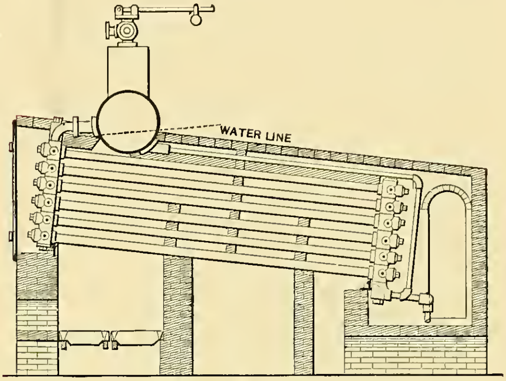
Nos. 8 and 9 are what were known as the Griffith & Wundrum boilers, afterwards merged into the Babcock & Wilcox. In these, experiments were made on four passages of the gases across the tubes, and the downward circulation of the water at the rear end of the boiler was carried to the bottom row of tubes. In No. 9, an attempt was made to reduce the amount of steam and water capacity, increase the safety and reduce the cost. A drum at right angle to the line of tubes



No. 8.

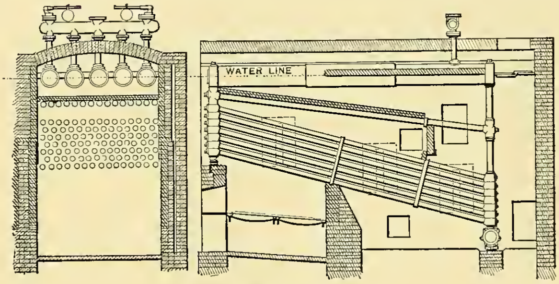
was tried, but as no provision was made for securing dry steam the results were not satisfactory, and the next move in the direction of safety was:

No. 10.—A nest of small horizontal drums, 15 inches in diameter, were used instead of the single drums of larger diameter; and a set



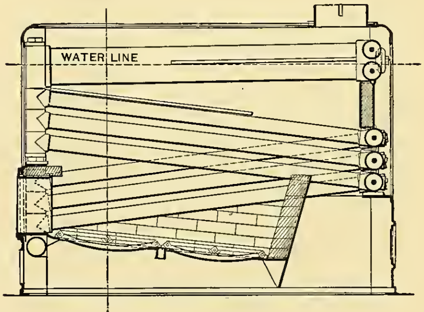
No. 9.

of circulation tubes were placed at an intermediate angle, between the main bank of heating tubes and the horizontal tubes which



No. 10.

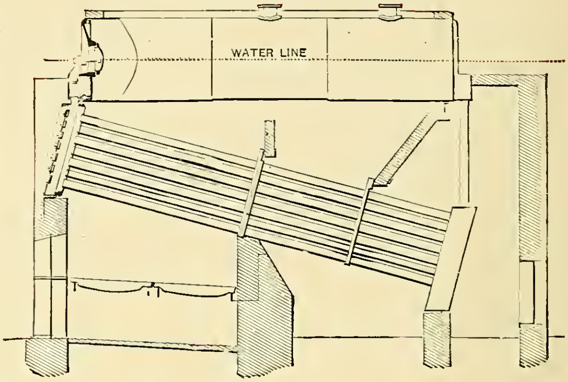
formed the steam reservoir, to return the water carried up by the circulation to the rear end of the heating tubes, allowing the steam only



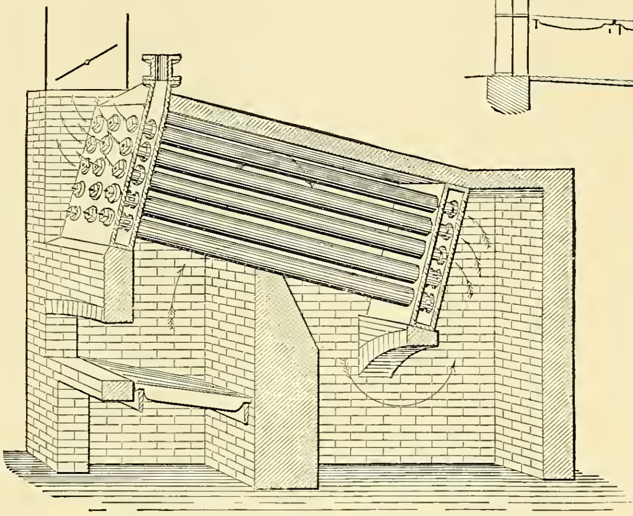
No. 11.

to be delivered into the small drums above. The result was no improvement in action over No. 9. The four passages of the gases did not add to the economy in either No. 8, 9, or 10.

No. 11.—A trial of a box coil system in which the water was made to traverse several times through the furnace before being delivered into the drum above. The tendency was, as in all similar boilers, to form steam in the middle of the coil and blow the water out from each end,



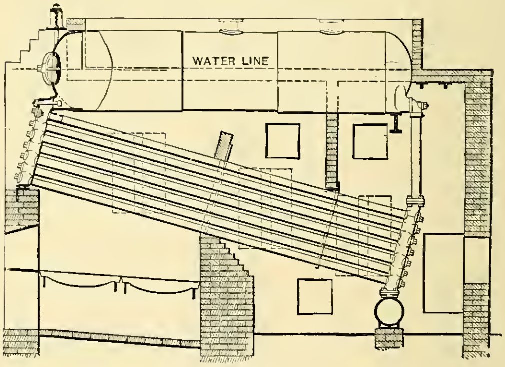
No. 14.


No. 12.

leaving the tubes practically dry until the steam found an outlet and the water returned. This boiler not only had a defective circulation but a decidedly geyser-like action, and produced wet steam.

All the above types, with the exception of Nos. 5 and 6, had a large number of bolted joints between their several parts and many of them leaked seriously, from unequal expansion, as soon as the heating surfaces became scaled; enough boilers having been placed at work to demonstrate their unreliability in this particular.

No. 12.—An attempt to avoid this difficulty and increase the heating surface in a given space. The tubes were expanded into both sides of wrought-iron boxes, openings being made in them for the admission of water and the exit of steam. Fire-tubes were placed inside these tubes

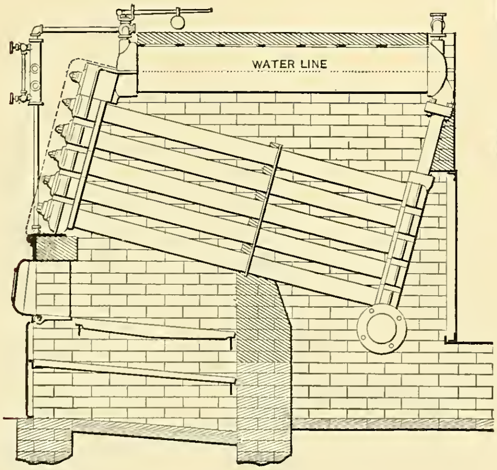


No. 15.

to increase the surface. These were abandoned because they quickly stopped up with scale, and could not be cleaned.

No. 13.—Water boxes formed of cast-iron of the full width and height of the bank of tubes were made of a single casting, which were bolted to the steam water-drum above.

No. 14.—A wrought-iron box was substituted for the cast-iron. In this, stays were necessary and were found, as is always the case, to be an element to be avoided wherever possible. It

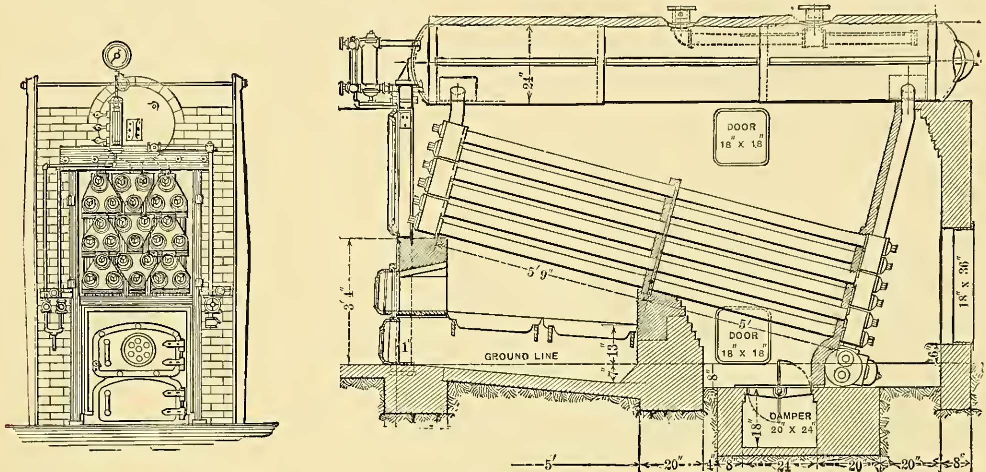


No. 13.

was, however, an improvement on No. 6. A slanting bridge wall underneath the drum was introduced to throw a larger portion of its surface into the first combustion chamber above the bank of tubes. This was found to be of no special benefit, and difficult to keep in good order.

No. 15.—Each vertical row of tubes was expanded at each end into a continuous header, cast of car wheel metal; the headers having a sinuous form so that they would lie close together and admit of a staggered position of the tubes in the furnace. This form of header has been found to be the best for all purposes, and has not since been materially changed. The drum was supported by girders resting on the brickwork. Bolted joints were discarded, with the exception of those connecting the headers to the front and rear end of the drum and the bottom of the rear header to the mud-drum. But even these bolted joints were found objectionable and were superseded in subsequent constructions by pieces of tube expanded into bored holes.

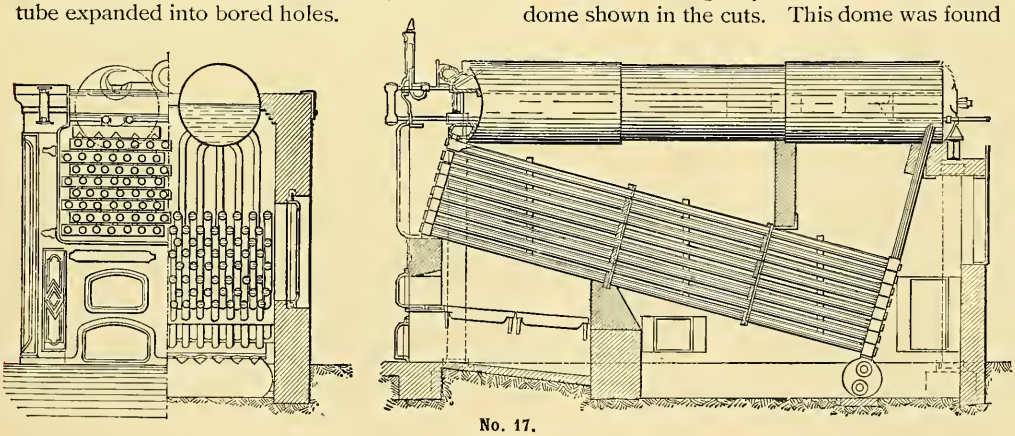
In No. 16 the headers were made in the form of triangular boxes, having three tubes in each. These were alternately reversed and connected together by short pieces of tube expanded in place, and to the drum by tubes bent so as to come normal to the shell. The joints between the headers introduced an element of weakness, and connections to the drum were insufficient to give the adequate circulation.



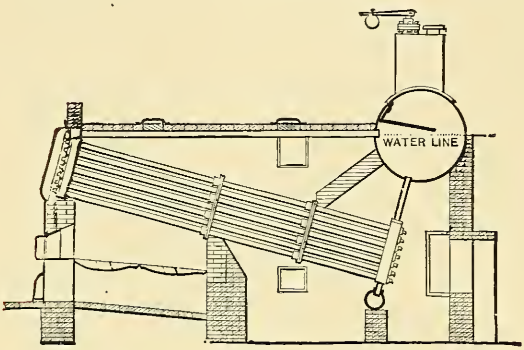
No. 16.

No. 17.—Straight horizontal headers were tried, alternately shifted right and left, to give a staggered position to the tubes. These headers were connected to each other and to the drum by expanded nipples. This was open to about the same objection as No. 16.

Nos. 18 and 19 were designed primarily for fire protection purposes, the requirements being a small compact boiler, and the ability to raise steam quickly. They both served their purpose admirably, but, as in No. 9, the only provision made for securing dry steam was the steam dome shown in the cuts. This dome was found


No. 17.

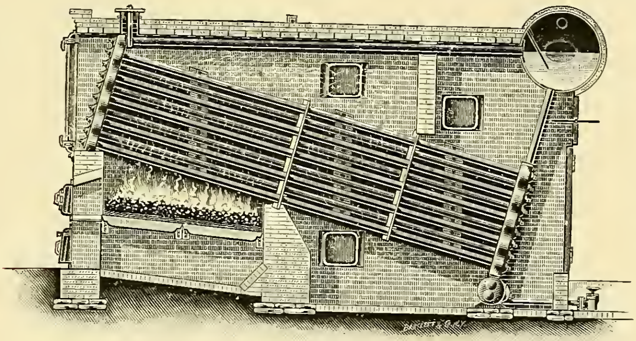
inadequate and has since been abandoned in nearly all forms of boiler construction. No other remedy being suggested at the time, they were not considered as desirable for general



No. 18.

use as the later construction shown in Nos. 21 and 22. In Europe, however, where small sizes were more in demand, No. 18 was modified and largely used with excellent results.

No. 20. The development of the B. and W.

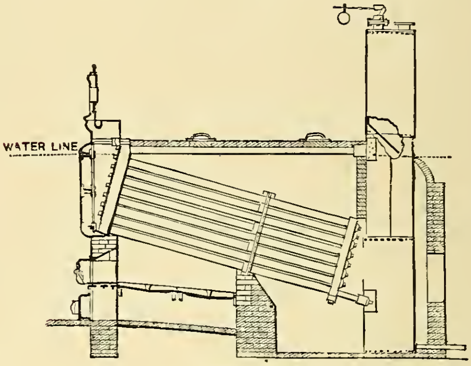


No. 20.

Marine boiler, in which the cross-drum is used exclusively, and the experience of our Glasgow works with No. 18 proved that proper attention to details of construction would make No. 18 a most desirable form for buildings where head room was limited, and with this in view No. 20 was designed, with the result that a large number of these boilers have been put in use under widely varying conditions without a single adverse report.

These experiments, as they may be called, although many boilers were built of some of the styles illustrated, clearly demonstrated that the best construction and efficiency required adherence to the following elements : —

1st. Sinuous headers for each vertical row of tubes. 2d. A separate and independent connection with the drum, both front and rear, for each such vertical row of tubes. 3d. All joints

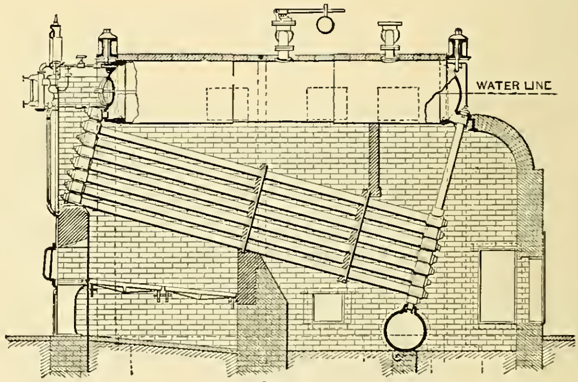


No. 19.

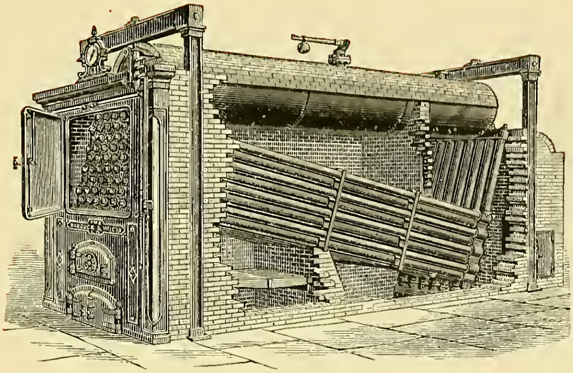
between the parts of the boiler proper to be made without bolts or screw-threads. 4th. No surfaces to be used which require to be stayed. 5th. The boiler supported independently of the brickwork, so as to be free to expand and contract as it was heated and cooled. 6th. The drums not less than 30 inches in diameter, except for small boilers. 7th. Every part accessible for cleaning and repair.

Having settled upon these points :

No. 21 was designed, having all these features, together with other improvements in the details of construction. The general form of construction of No. 15 was adhered to, but short pieces of boiler tube were used as connections between the sections and drum, and mud-drum ; their ends being expanded into adjacent parts with a Dudgeon



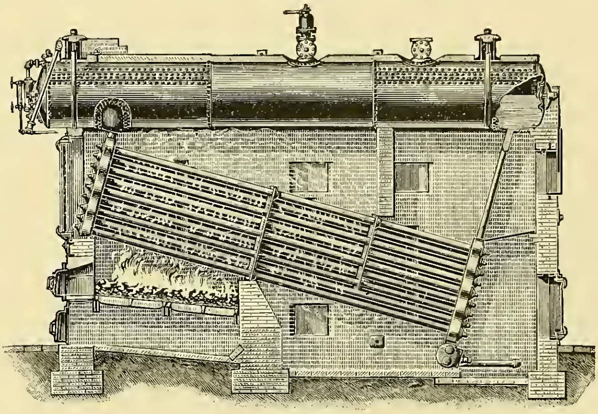
No. 21.



No. 21.

expander. This boiler was also suspended entirely independent of the brickwork by means of columns and girders, and the mutually deteriorating strains where one was supported by the other were avoided.

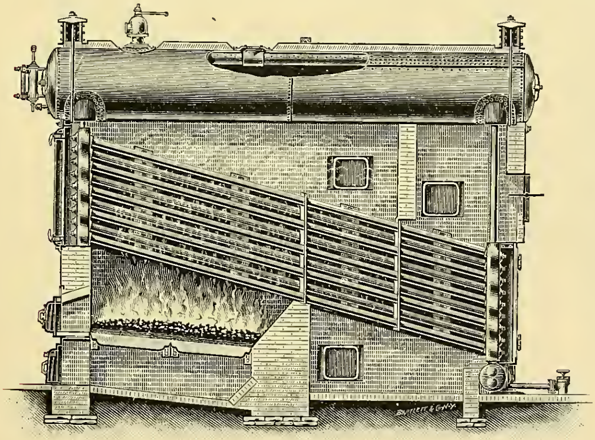
Since this construction was adopted hundreds of thousands of horse-power of this style have been built, giving excellent satisfaction. It is known as our "C. I. F." (cast-iron front) style, a fancy cast-iron front being generally used therewith, as shown in the perspective view. Recent investigations have shown that the average cost of up-keep of the boiler proper is *less than five cents per horse-power per annum.*



No. 22.

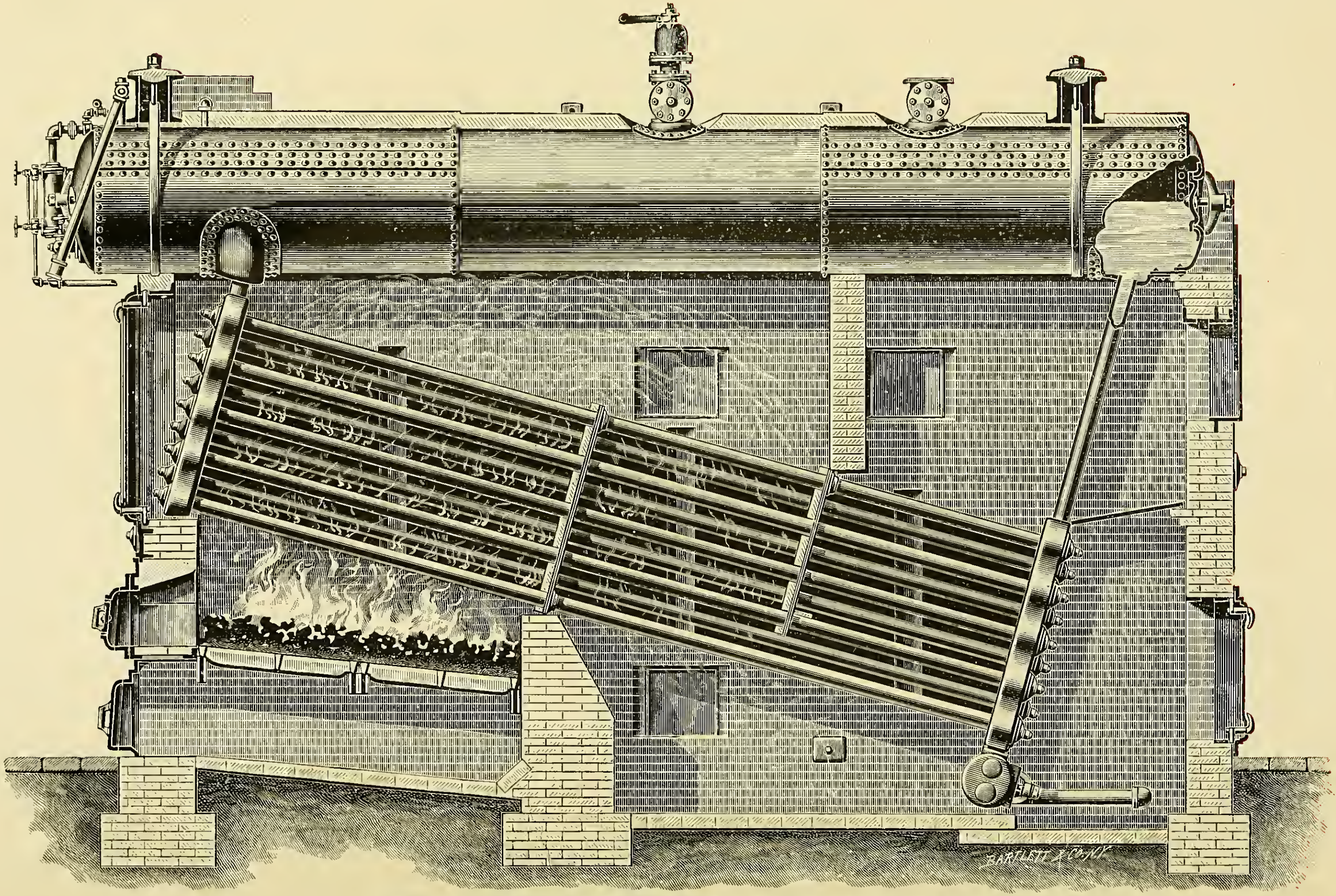
No. 22 is known as our "W. I. F." style, the front usually supplied with it being largely made of wrought-iron. In this boiler, flanged and "bumped" drum heads of wrought-steel are used; the drum is longer, and the sections are connected to cross-boxes riveted to its bottom. Where height is to be saved, the steam is taken out through nozzles placed on the drum heads. In this style also the drum is suspended from columns and girders.

No. 23. The "Vertical Header Style" has the same general features of construction with the exception of having the tube-sheet side of the header "stepped" so that the header may be placed at right angles to the drum, instead of having it inclined as in Nos. 21 and 22. This form permits of a shorter brick setting, thereby reducing the cost of erection and the floor space occupied. Nos. 20, 22, and 23 have now become the standard forms, although No. 21 is still furnished occasionally.



No. 23.

The last step in the development of the water-tube boiler, beyond which it seems almost impossible for science and skill to go, consists in making *all parts of the boiler of wrought-steel,* including the sinuous headers, the cross-boxes, and the nozzles on the drum. This was demanded to answer the laws of some of the Continental Nations, and the Babcock & Wilcox Co. have, at the present time, a plant turning out forgings, as a regular business, which have been pronounced by the *London Engineer* to be "a perfect triumph of the forgers' art."



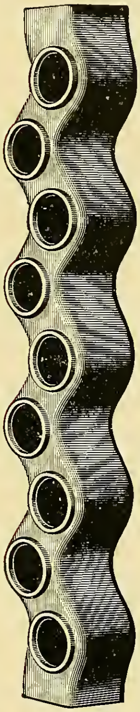
Side View of Babcock & Wilcox Boiler of Wrought Steel Construction.

DESCRIPTION OF THE BABCOCK & WILCOX WATER-TUBE BOILER

F·B·A· N·Y·

CONSTRUCTION.

THIS boiler is composed of lap-welded wrought iron tubes, placed in an inclined position and connected with each other, and with a horizontal steam and water drum, by vertical passages at each end, while a mud-drum is connected to the rear and lowest point in the boiler.



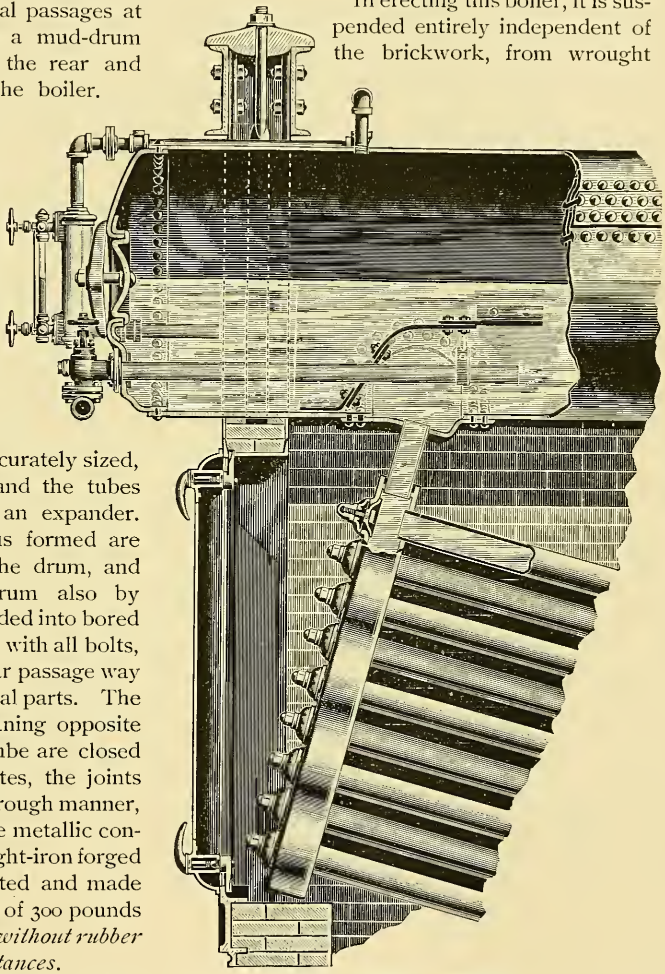
END VIEW OF HEADER.

The end connections are in one piece for each vertical row of tubes, and are of such form that the tubes are "staggered" (or so placed that each row comes over the spaces in the previous row). The holes are accurately sized, made tapering, and the tubes fixed therein by an expander. The sections thus formed are connected with the drum, and with the mud-drum also by short tubes expanded into bored holes, doing away with all bolts, and leaving a clear passage way between the several parts. The openings for cleaning opposite the end of each tube are closed by hand-hole plates, the joints of which are made in the most thorough manner, by milling the surfaces to accurate metallic contact, and are held in place by wrought-iron forged clamps and bolts. They are tested and made tight under a hydrostatic pressure of 300 pounds per square inch, *iron to iron, and without rubber packing, or other perishable substances.*

The steam and water drums are made of flange iron or steel, of extra thickness, and double riveted. They can be made for any desired pressure, and are always tested at 50% above the pressure for which they are constructed. The mud-drums are of cast-iron, as the best material to withstand corrosion, and are provided with ample means for cleaning.

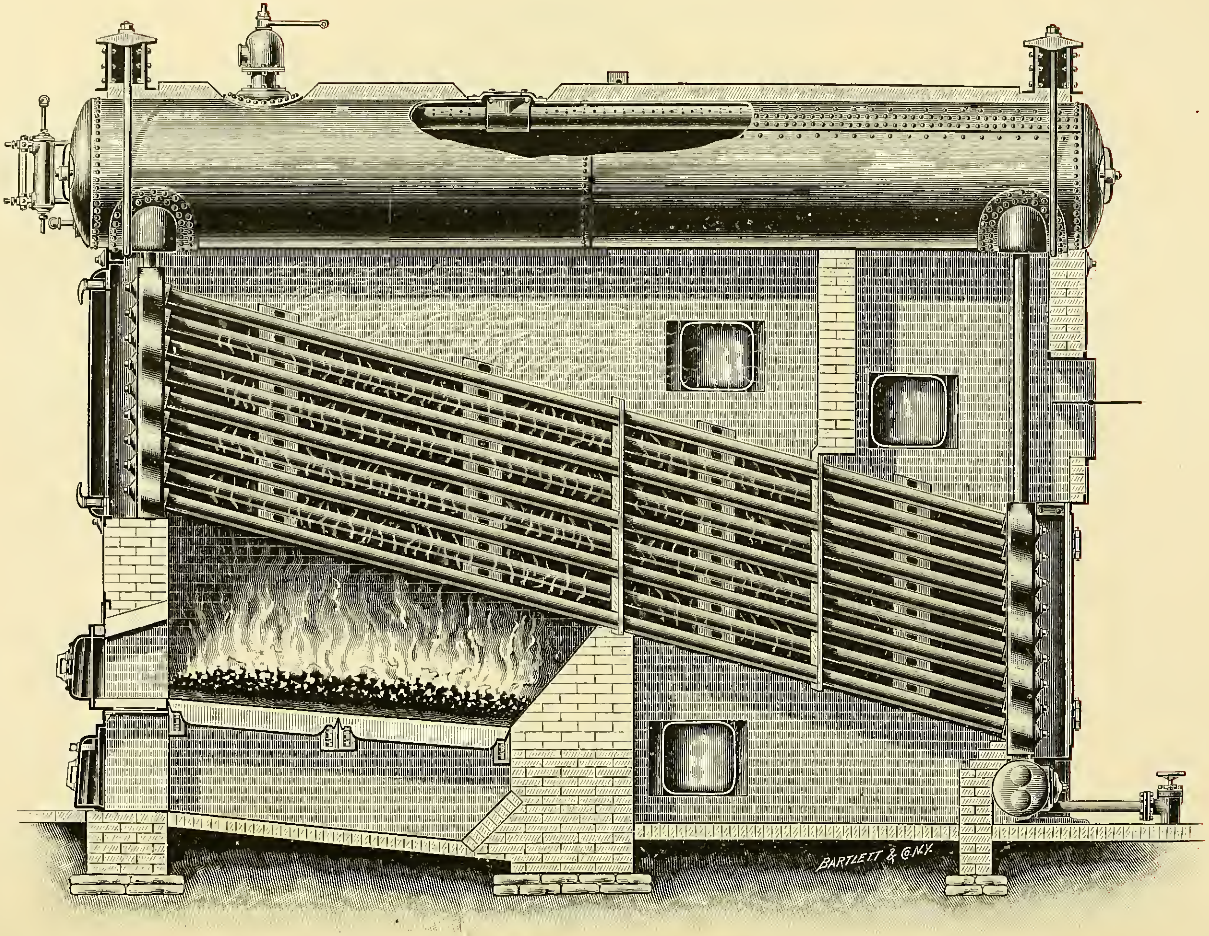
ERECTION.

In erecting this boiler, it is suspended entirely independent of the brickwork, from wrought



PARTIAL VERTICAL SECTION.

iron girders resting on iron columns. This avoids any straining of the boiler from unequal expansion between it and its enclosing walls, and permits the brickwork to be repaired or removed, if necessary, without in any way dis-

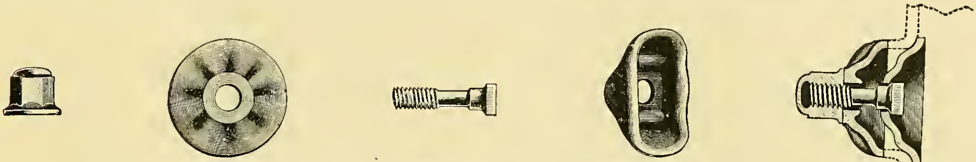


Side View of Vertical Header Boiler.

turbing the boiler. All the fixtures are extra heavy and of neat designs.

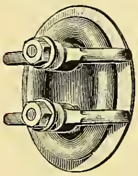
OPERATION.

The fire is made under the front and higher end of the tubes, and the products of the combustion pass up between the tubes into a combustion chamber under the steam and water drum; from thence they pass down between the tubes, then once more up through the spaces between the tubes, and off to the chimney. The water inside the tubes, as it is heated, tends to rise towards the higher end, and as it is converted into steam—the mingled column of steam and water being of less specific gravity than the solid water at the back end of the boiler—rises through the vertical passages into the drum above the tubes, where the steam separates from the water and the latter flows back to the rear and down again through the tubes in a continuous circulation. As the passages are all large and free, this



Forged Steel Header Hand Hole Fittings.

circulation is very rapid, sweeping away the steam as fast as formed, and supplying its place with water; absorbing the heat of the fire to the best advantage; causing a thorough commingling of the water throughout the boiler and a consequent equal temperature, and preventing, to a great degree, the formation of deposits or incrustations upon the heating surfaces, sweeping them away and depositing them in the mud-drum, whence they are blown out.



Forged Steel Manhole Plate.

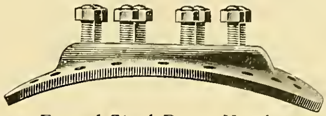
The steam is taken out at the top of the steam-drum near the back end of the boiler after it has thoroughly separated from the water, and to insure dry steam a perforated dry-pipe is connected to the nozzle inside the drum.

ADVANTAGES.

The following are the prominent advantages which this boiler presents over those of the ordinary construction:—

1.—Thin Heating Surface in Furnace.

The thick plates necessarily used in ordinary boilers, in the furnace, or immediately exposed to the fire, not only hinder the transmission of heat to the water, but admit of overheating, and even burning the side next the fire, with consequent strains, resulting in loss of strength, cracks, and tendency to rup-



Forged Steel Drum Nozzle.

ture. This is admittedly the direct cause of many explosions. Water-tubes, however, admit of thin envelopes for the water next the fire, with such ready transmission of heat that even the fiercest fire cannot overheat or injure the surface, as long as it is covered with water upon the other side.

2.—Joints Removed from the Fire.

Riveted joints with their consequent double thickness of metal, in parts exposed to the fire, give rise to serious difficulties. Being the weakest parts of the structure, they concentrate upon themselves all strains of unequal expansion, giving rise to frequent leaks, and not rarely to actual rupture. The joints between tubes and tube sheets also give much trouble when exposed to the direct fire, as in locomotive and tubular boilers. These difficulties are wholly overcome by the use of lap-welded water-tubes, with their joints removed from the fire.

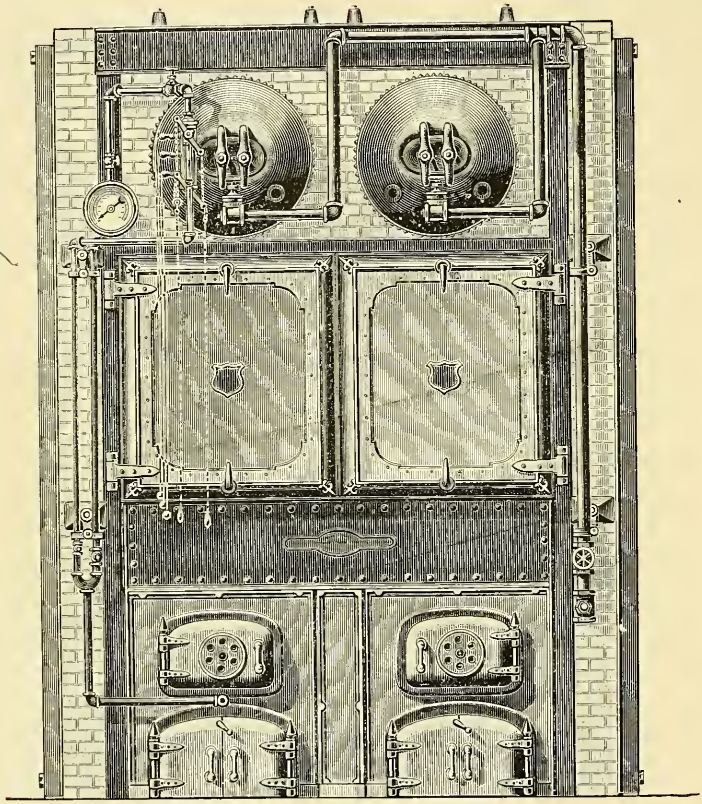
3.—Large Draft Area.

This, which is limited in fire-tubes to the actual area of the tubes, in this boiler is the whole chamber within which the tubes are enclosed, which, with down draft, gives ample time in the passage of the heated gases to the chimney for thorough absorption of their heat.

4.—Complete Combustion.

The perfection of combustion depends upon a thorough mixture of the gases evolved from the burning of fuel with a proper quantity of atmospheric air; but this perfect mixture rarely occurs in ordinary furnaces, as is proved by chemical analysis, and also by the escape of smoke, upon the introduction of any smoke-producing fuel. Even when smoke is not visible a large percentage of the combustible gases may be escaping into the chimney, in the form of carbonic oxide, or half-burned carbon. Numerous attempts have been made to cure this evil, by admitting air to the furnace or flues, to "burn the smoke"; but though this may allow so much air to mingle with the smoke as to render it invisible, and at the same time ignite some of the lighter gases, it in reality does little to promote combustion, and the cooling effect of the air more than over-balances all the advantages resulting from the burning gas. The analysis of gases from various furnaces shows almost uniformly an excess of free oxygen, proving that sufficient air is admitted to the furnace, and that a more thorough and perfect *mixing* is needed. Every particle of gas evolved from the fuel should have its equivalent of oxygen, and must find it while hot enough to combine, in order to be effective. In this boiler the currents of gases after leaving the furnace are broken up and thoroughly mingled by passing between the staggered tubes, and have an opportunity to complete their combustion in the triangular chamber between the tubes and drum.

That this does really take place is proved by an analysis by Dr. Behr of the escaping gases from a stack of these boilers at Mattheissen & Weicher's sugar refinery. He made many separate analyses at different times, and in no case was there more than a trace of carbonic oxide, even when there was less than one per cent. of uncombined oxygen.



Standard Front of Babcock & Wilcox Boiler.

5.—Thorough Absorption of the Heat.

There are important advantages gained in this respect in consequence of the course of the gases being more nearly at right angles to the heating surface, impinging thereon instead of gliding by in parallel lines as in fire-tube boilers. The currents passing three times across and between the staggered tubes are brought intimately in contact with all parts of the heating surface, rendering it much more efficient than the same area in ordinary tubular boilers.

The experiments of Doctor Alban and of the U. S. Navy have proved that a given surface arranged in that manner is thirty per cent. more efficacious than when in the form of fire tubes as usually employed.

6.—Efficient Circulation of Water.

As all the water in the boiler tends to circulate in one direction, there are no interfering currents, the steam is carried quickly to the surface, all parts of the boiler are kept at a nearly equal temperature, preventing unequal strains, and by the rapid sweeping current the tendency to deposit sediment on the heating surface is materially lessened.

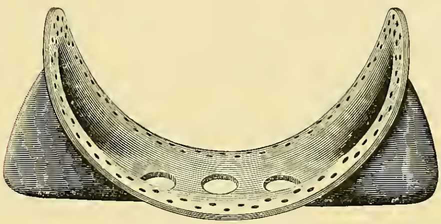
7.—Quick Steaming.

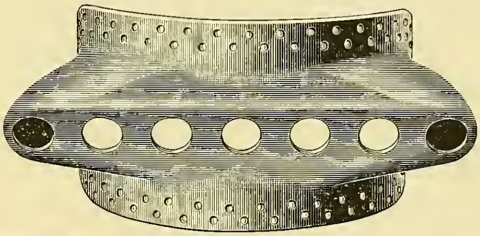
The water being divided in many small streams, in thin envelopes, passing through the hottest part of the furnace, steam may be rapidly raised in starting, and sudden demands upon the boiler may be met by a quickly increased efficiency.

and the ample passages for circulation, secure a steadiness of water level not surpassed by any boiler. This is a most important point in boiler construction and should always be considered when comparing the horizontal and vertical types of water-tube boilers. Take, for instance, a Babcock and Wilcox boiler of 250 H.P. and a well known vertical water-tube boiler. The former lowers its water line at the rate of one inch in 5.87 minutes, and the latter at the rate of one inch in 1.15 minutes. Or if we suppose the feed pumps to break down when the boilers are running at their rated capacity and the water line is at the normal height, it will be one hour and 23 minutes before the water is all out of the drum of the B. & W. boiler, while with the vertical boiler the crown sheet will be bare in 20.9 minutes.

10.—Freedom of Expansion.

The arrangement of the parts, forming a flexible structure, allows any member to expand without straining any other, the expanded con-





Forged Steel Cross Box.

8.—Dryness of Steam.

The large disengaging surface of the water in the drum, together with the fact that the steam is delivered at one end and taken out at the other, secures a thorough separation of the steam from the water, even when the boiler is forced to its utmost. Most tubular, locomotive, and sectional boilers make wet steam, "priming" or "foaming," as it is called, and in many "super-heating surface" is provided to "dry the steam"; but such surface is always a source of trouble, and is incapable of being graduated to the varying requirements of the steam. No part of a boiler not exposed to water on the one side should be subjected to the heat of the fire upon the other, as the unavoidable unequal expansion necessarily weakens the metal, and is a serious source of danger. Hence a boiler which makes dry steam is to be preferred to one that dries steam which has been made wet.

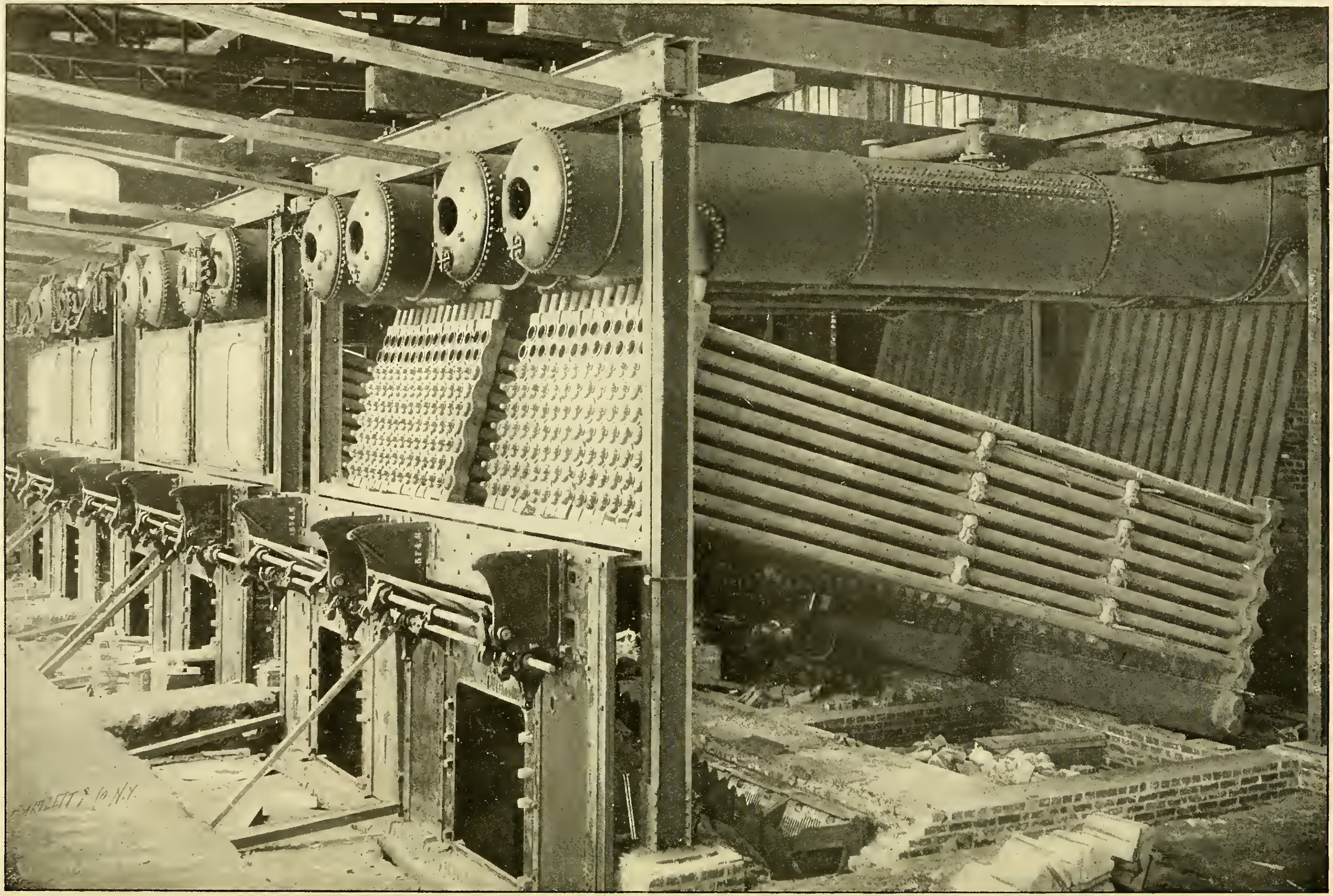
9.—Steadiness of Water Level.

The large area of surface at the water line,

nections being also amply elastic to meet all necessities of this kind. This is of great importance because the weakening effect of these strains of unequal expansion, between rigidly connected parts, is a prolific cause of explosions in ordinary boilers. The rapid circulation of the water, however, in this boiler, by keeping all parts at the same temperature, prevents to a large extent unequal expansion.

11.—Safety from Explosions.

The freedom from unequal expansion avoids the most frequent cause of explosions, while the division of the water into small masses prevents serious destructive effects in case of accidental rupture. The comparatively small diameter of the parts secures, even with thinness of surface, great excess of strength over any pressure which it is desirable to use. So powerful is the circulation of the water, that no part will be uncovered to the fire until the quantity of water in the boiler is so far reduced that if overheating should occur no explosion could result.



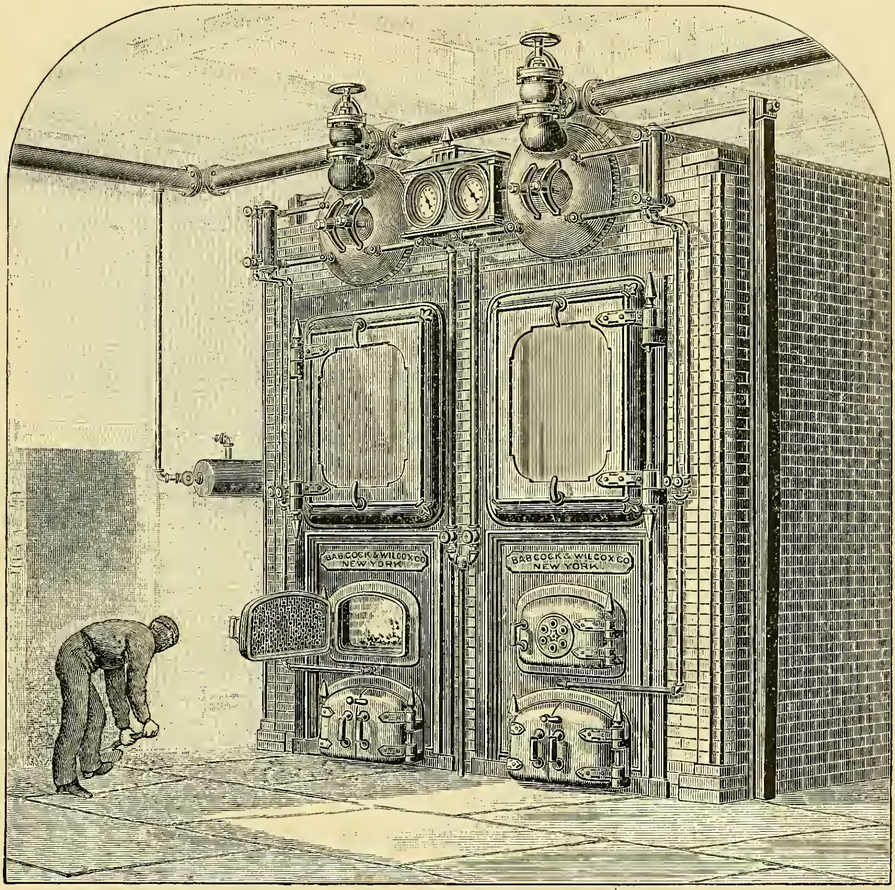
1600 H. P. Babcock & Wilcox Boilers in process of erection in Pacolet Mills, Gainesville, Ga.

12.—Capacity.

This is a point of the greatest importance, and upon it depends, in a large measure, the satisfactory performance of any boiler in several particulars. Unless sufficient steam and water capacity is provided there will not be regularity of action; the steam pressure will suddenly rise and as suddenly fall, and the water level will be subject to frequent and rapid changes; and if the steam is drawn suddenly from the boiler, or the boiler crowded, wet steam will result.

Water capacity is of more importance than steam space, owing to the small relative weight of the steam. *Twenty-three* cubic feet of steam, or *one* foot of water space, are required to supply *one horse-power for one minute*, the pressure meantime falling from 80 pounds to 70 pounds per square inch. The value of large steam room is therefore generally much overrated, but if it be too small the steam in passing off will sweep the water with it in the form of spray. Too much water space makes slow steaming and waste of fuel in starting. Too much steam space adds to the radiating surface and increases the losses from that cause. The proportions of this boiler have been adopted after numerous experiments with boilers of varying capacity; and experience has established that this boiler can be driven to the utmost, carrying a steady water level, and steam pressure, and always furnishing dry steam.

The cubical capacity of this boiler, per horse-power, is equal to that of the best practice in tubular boilers of the ordinary construction. The fire surface being of the most effective character, these boilers will, with good fuel and a reason-



Babcock & Wilcox Boilers, 164 H.P. Erected 1884, for Greenfield & Co., Confectioners, Brooklyn, N.Y. 164 H.P. additional erected in 1890.

ably economical engine, greatly exceed their rated power, though it is seldom economy to work a boiler above its nominal power. The space occupied by this boiler and setting is equal to about two-thirds that of the same power in fire tubular boilers.

13.—Accessibility for Cleaning.

This is of the greatest importance and is secured to the fullest extent. Hand-holes, with metal joints, opposite each end of each tube, permit access thereto for cleaning, and a man-hole in the steam and water drum, and hand-holes in mud-drum, are provided for the same purpose. All portions of both the exterior and interior surface are fully accessible for cleaning. The occasional use of steam through a blowing pipe attached to a rubber hose operated through doors in the side walls, will keep the tubes free from soot and in condition to receive the heat to the best advantage.

14.—Least Loss of Effect from Dust.


WATER-TUBE.


FIRE-TUBE.

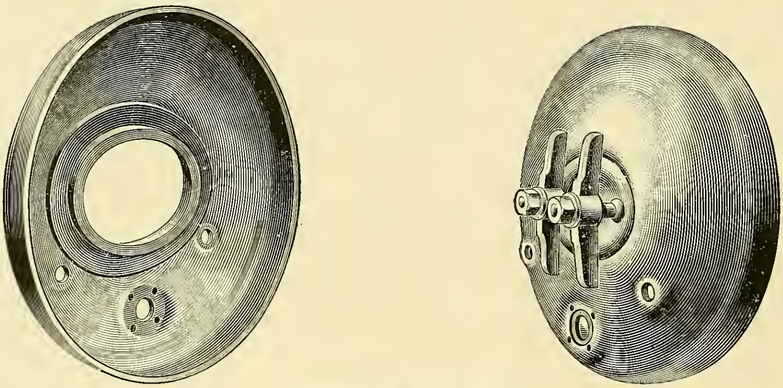
The ordinary fire-tube, or flue, receiving the dust from the fire on the interior is quickly covered from one-third to one-half its surface, and in time is completely filled. The water-tube, however, will retain but a limited quantity on its upper side, after which it becomes in a measure self-cleaning.

15.—Durability.

Besides the important increase of durability due to the absence of deteriorating strains, and of thick plates and joints in the fire, there is no portion of the boiler exposed to the abrasive action which so rapidly destroys the ends of fire tubes, or to the blow-pipe action of the flame upon the crown sheet, bridge walls, and tube sheets, which are so destructive frequently to ordinary, particularly locomotive, boilers. Neither is there any portion of the surface above the water level exposed to the fire. For these reasons these boilers are durable, and less liable to repairs, than other boilers under the same circumstances, and having the same care.

16.—Ease of Transportation.

Being made in sections, which are readily put together with a simple expanding tool, these boilers may be easily and cheaply transported where it would be impossible to place a boiler of ordinary construction. They can be made in parts small enough for mule transportation, if required.



Forged Steel Drum Head.

17.—Repairs.

As now constructed these boilers seldom require repairs, but if, from any cause, such should be necessary, any good mechanic can make them with the tools usually found in boiler shops. Should a tube require to be renewed it can be removed, and a new one substituted the same as in a tubular boiler.

18.—Practical Experience.

The above advantages would be worthy of attention if they were only theoretical, but they have been, in fact, demonstrated by the experience of twenty years, under a great variety of circumstances and of treatment. Of the total number sold, less than two per cent. have, so far as we are aware, been thrown out of use; while a large number of customers have repeated their orders,—some a score of times,—as will be seen by the list of references hereto appended.

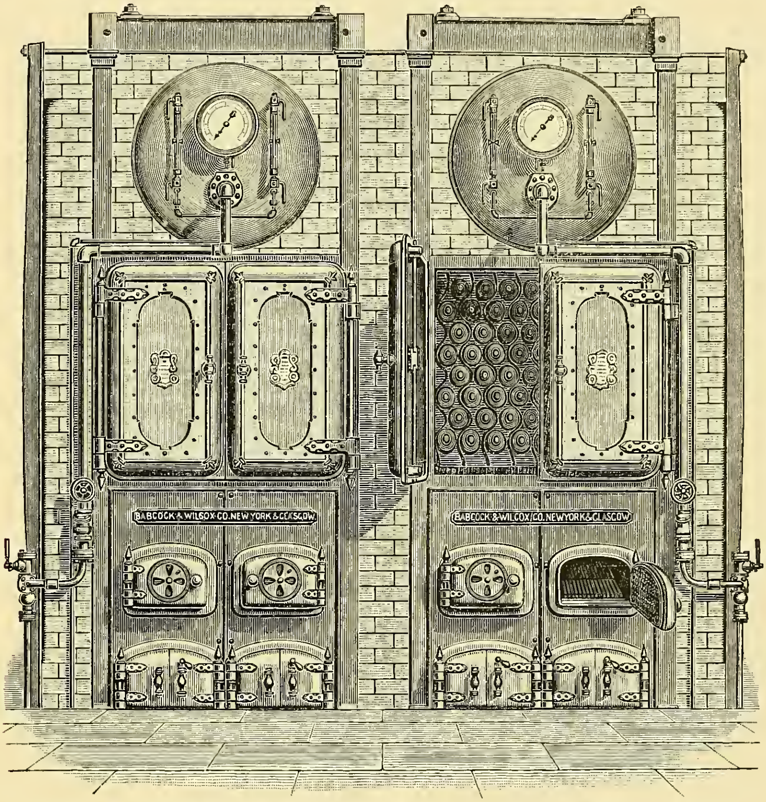
RULES AND PRACTICAL DATA.

ECONOMY IN STEAM.

Efficiency of the Boiler.

One pound of pure carbon when burned yields 14,500 heat units, each of which is equal to 778 foot pounds of energy. If all its heat was utilized in power, it would therefore exert 5,697 horse-power for one hour, instead of from ½ to ¼, as in the best ordinary practice. The 14,500 heat units would, if all utilized in a boiler, evaporate 15 pounds of water from 212° at atmospheric pressure. A boiler which evaporates 7½ pounds of water for each pound of combustible utilizes but 50 per cent. of the total heat, and this is about the average result of shell boilers now in use.

The Babcock & Wilcox boilers, in *thirty tests* extending over the last twelve years, under a great variety of conditions and circumstances, by no less than twenty different engineers, and, with only two exceptions, on boilers in daily use for manufacturing purposes, in England, Scotland, and from Massachusetts to California in the United States, with various kinds and grades of coals, and at various rates of combustion, covering an aggregate of nearly three months' regular working, and evaporating over three thousand tons of water, gave an average evaporation of 11.4217 pounds water per pound of combustible. This is within *four per cent.* of Rankine's standard, *and within seven and one-half per cent. of the highest theoretical efficiency*, under the conditions in which they were made. It is not probable that any kind of boiler, fairly tested, will ever beat such a record. As about 15 per cent. is lost in the chimney gases, and in

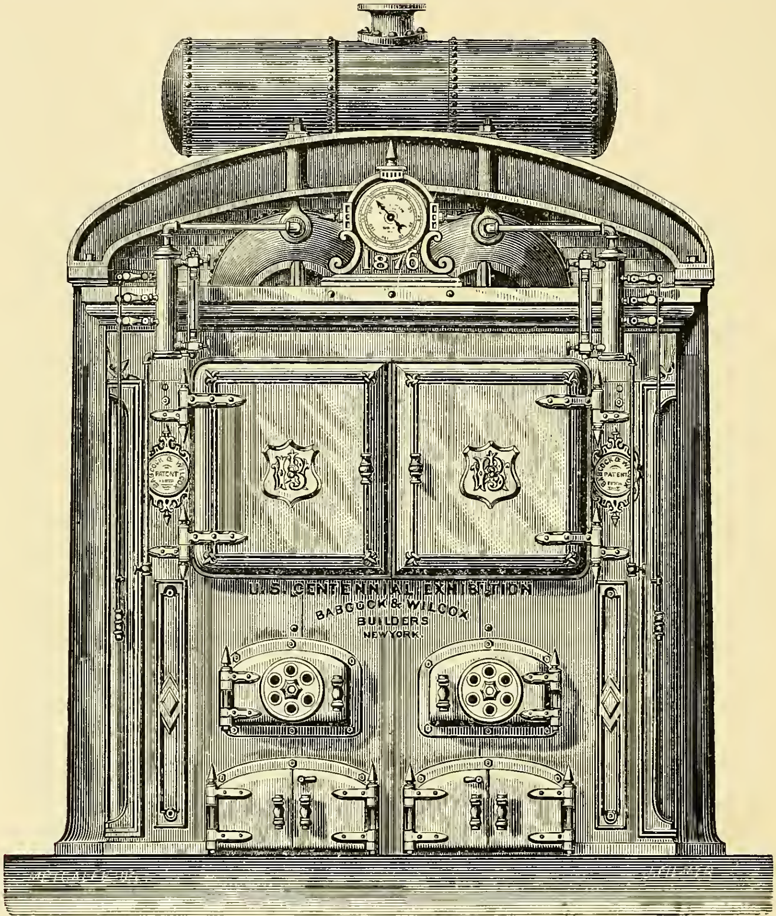


Babcock & Wilcox Boiler at Chavanne Brun et Cie., Chamond, France. 248 H.P.
"W. I. F." style, with Wrought Headers.

radiation, it is evident that all claims to over 12½ pounds evaporation should be looked upon as unreliable.

A steam generator is composed of two distinct parts, each with its independent function. The furnace is for the proper combustion of the fuel, and its duty is performed to perfection when the greatest amount of heat is obtained from the given weight of combustible. The boiler proper is for the transfer of the heat thus generated into useful effect by evaporating water into steam, and its function is fulfilled completely when the greatest possible quantity of heat is thus utilized. To a lack of appreciation of this fact, and of a knowledge of the principles involved, is chargeable much waste of money and disappointment, both to inventors and steam users.

As a boiler is for making steam, it can only utilize for that purpose heat of a greater intensity or higher temperature than the steam itself, therefore the gases of combustion cannot be reduced below that temperature, and the heat thereby represented is lost. The amount of this loss will depend upon the amount of air admitted to the furnace, and the increase of temperature at which it escapes. The more air admitted the greater the loss; hence the fallacy of all those schemes which admit air above the fire.



FRONT VIEW.

Babcock & Wilcox Boiler at U. S. Centennial Exhibition, 1876. 150 H.P.

"The maximum conductivity or flow of heat is secured by so designing the boiler as to secure rapid, steady, and complete circulation of the water within it . . . and securing opposite directions of flow for the gases on the one side and the water on the other."—*Prof. R. H. Thurston.*

The accumulation of scale on the interior, and of soot on the exterior, will seriously affect the efficiency and economy of the boiler. The amount of loss due to these causes has been variously estimated and the best authorities seem to hold that only one-eighth of an inch deposit of soot renders the heating surface practically useless, and only one-sixteenth of an inch of scale or sediment will cause a loss of 13 per cent. in fuel, but while these figures may be wide of the truth yet the loss is undoubtedly very large. The loss due to incrustation of scale will vary with the chemical composition and porosity of the deposit. A boiler must, therefore, be kept clean, outside and in, to secure a high efficiency.

It is never economy to force a boiler, and the best results are always attained with ample boiler power. It is also necessary to keep the boiler, together with its brickwork, in good order, and to have careful firing where economy is desired.

The result of a bad setting for a boiler has been known to be a loss of 21 per cent. in economy.

Efficiency of the Furnace.

Combustion may be defined as "the union of two dissimilar substances, evolving light and heat." In ordinary practice, one of these is always the oxygen in the atmosphere, and the other is the fuel employed. Every pound of fuel requires a given quantity of oxygen for its complete combustion, and thus a given quantity of air. This varies with different fuels, but in every case less air prevents complete combustion, and an excess of air causes waste of heat to the amount required to heat it to the temperature of the escaping gas.

With chimney draft, the experiments of the U. S. Navy show that ordinary furnaces require about twice the theoretical amount of air to secure perfect combustion.

Prof. Schwackhoffer, of Vienna, found in the boilers used in Europe an average excess of 70 per cent. of the total amount passing through the fire—or that over three times the theoretical amount was used.

A series of analyses by Dr. Behr of the escaping gases from a Babcock & Wilcox boiler, with chimney draft, showed an average excess of air equal to 48 per cent. of the whole quantity.

A series of 12 tests made by same with artificial blast gave an average excess of only 22 per cent. of the whole quantity, and in a few cases none at all, with only traces of carbonic oxide, showing perfect combustion.

In a summary of experiments made in England, published in Bourne's large work, "Steam, Air, and Gas Engines," it is stated:—

"A moderately thick and hot fire with rapid draft uniformly gave the best results."

"Combustion of black smoke by additional air was a loss."

"In all experiments the highest result was always obtained when all the air was introduced through the fire bars."

"Difference in mode of firing only may produce a difference of 13 per cent." (in economy).

Different fuels require different furnaces, and no one furnace or grate-bar is equally good for all fuels. The Babcock & Wilcox Co. provide with their boilers, a special furnace, adapted to the particular kind of fuel to be used.

Efficiency of the Engine.

The efficiency of the steam engine is often based on the amount of fuel burned per indicated horse-power per hour; but it is more properly based on the steam consumption. The highest class of steam engines running condensing will use under test conditions from twelve to twelve and one-half pounds of water in the form of steam per I. H. P. per hour, while the ordinary automatic cut-off engine with single expansion, non-condensing, uses from 28 to 35 pounds. The fuel used per horse-power hour therefore depends on the quality of coal and the efficiency of the boiler and furnace as well as upon the efficiency of the engine.

A good boiler properly set and fired will show a much higher percentage of efficiency than the engine. When operated with high-grade fuel and under the best conditions a boiler may deliver to the engine as much as 75% of the theoretical heat of the coal, and if the coal contain 14,500 British thermal units per pound this is equivalent to 9.78 pounds of water evaporated from a feed temperature of 120° Fahr. to steam at 200 pounds gauge pressure. If the engine use 12 pounds of steam per horse-power hour this means a coal consumption of 1.23 pounds per I. H. P. per hour; or if the engine use 30 pounds of steam, a coal consumption of 3.07 pounds. These figures if transposed for efficiency would be about as follows: one pound of coal having 14,500 B.T.U. is equivalent to 11,281,000 foot pounds, which on a supposition of 75% efficiency in the boiler, is equal to 8,460,750 foot pounds, which if all utilized by the engine would produce 4.29 H.P. for one hour, or at the rate of .233 pounds of coal per H. P. per hour instead of the amounts above stated. On this basis the highest class engine has an efficiency of scarcely 19%, and the other of a little more than 7½%, and the efficiency of engine and boiler combined is but 14¼% and 5.7% respectively.

It is economy, therefore, in most cases, to use a high-class engine. There are instances, however, where the engine is used for so short a time in each year, that the saving may not be sufficient to pay the interest on the additional cost, and a cheaper engine, even if comparatively wasteful, may be better economy.

Compound engines, when high pressures can be obtained, have an advantage in economy over single cylinders, and "triple" and "quadruple" expansion engines under some conditions show a saving over simple "compound." But they require a pressure of from 150 to 200 pounds, and a comparatively steady load, to develop their advantages to a great degree. Such pressures can be safely carried on Babcock & Wilcox boilers.

A large boiler is generally an advantage, but it is not economy to use a large engine to develop a small power. Sufficient steam to fill the cylinder at the terminal pressure—each stroke—has to be furnished whether the engine is doing more or less work, and this frequently amounts to far more than the steam used to do the work. Thus, a 24 X 48 engine, making 60 revolutions per minute, without "cut-off," uses 30 horse-power of steam in displacing the atmosphere, without exerting any available power. For the same reason back pressure greatly increases the cost of the power.

Efficiency of Pumping Engines.

The duty of the different types of steam actuated pumps and pumping engines is the measure of their efficiency expressed in work done per unit of steam, fuel, or heat consumed in their operation.

On the basis of the unit recommended by the American Society of Mechanical Engineers, it is the number of foot pounds of work done, as represented by the weight in pounds of liquid pumped multiplied by the head in feet against which it is pumped, for each 1,000,000 British thermal units furnished by the boiler and indicated by the weight and temperature of the feed water and the pressure and quality of the steam used.

Or, assuming the use of a good grade of coal and an efficient boiler and furnace, the duty of a pumping engine is the amount of work done as measured at the pump plungers for each 100 pounds of coal consumed on the grates, or for each 1035.5 pounds of steam consumed, measured from and at 212° Fahr. The evaporation of 1035.5 pounds of water, from and at 212° Fahr., requires the transfer of 1,000,000 British thermal units.

The boiler horse-power and consequent fuel consumption required for a given pumping service performed varies greatly with the type of steam end used to actuate the pumps, as shown by the following table:—

RELATIVE EFFICIENCY OF DIFFERENT TYPES OF PUMPING ENGINES.

Type.		Duty. Million foot pounds work done per 1000 pounds steam consumed, with varying conditions of service.	Pounds of Steam. Per pump horse power per hour.
Condensing.			
Direct acting and crank and fly-wheel,	Triple expansion, .	125 to 140	16 to 13.5
Direct acting and crank and fly-wheel,	Compound, . . .	100 to 120	20 to 16
Direct acting low duty, ...	Triple expansion, .	75 to 90	26 to 20
Direct acting low duty, ...	Compound, . . .	40 to 60	50 to 33
Non-Condensing.			
Direct acting low duty, ...	Triple expansion, .	50 to 70	40 to 28
Direct acting low duty, ...	Compound, . . .	30 to 40	66 to 50
Direct acting small sizes, ...	Non-Compound, .	8 to 20	250 to 100
Vacuum pumps, direct acting, independent		8 to 20	250 to 100
Vacuum pumps, fly wheel, independent, ...		45 to 80	45 to 25
Injectors, ...		2 to 5	1000 to 400

FUEL.

The value of any fuel is measured by the number of heat units which its combustion will generate, a unit of heat being the amount required to heat one pound of water one degree Fahrenheit. "Combustible" is that portion which will burn; the ash or residue varying from 2 to 36 per cent. in different fuels.

All of the fuels used for generating steam depend for their heating value upon the amount they contain of the two chemical elements, carbon and hydrogen. Solid fuels, such as coal and wood, contain, in addition to these useful elements, other substances which have no heating value, such as ash, water, and oxygen, the oxygen being in chemical combination with the hydrogen and carbon. Most coals contain also small percentages of sulphur (usually in the form of iron pyrites) and of nitrogen, which are of no value as fuel. Liquid fuels, such as petroleum and its products, are nearly pure compounds of carbon and hydrogen, and gaseous fuels contain carbonic oxide, hydro-carbon gases, and hydrogen as their heat-giving substances, with other constituents which are of no value and which vary greatly in amount in different gases, as carbonic acid, nitrogen, and occasionally oxygen.

TABLE OF COMBUSTIBLES.

Kind of Combustible.	Air Required.	Temperature of Combustion.				Theoretical Value.		Highest Attainable Value under Boiler.	
	In Pounds, per pound of Combustible.	With Theoretical Supply of Air.	With 1½ Times the Theoretical Supply of Air.	With Twice the Theoretical Supply of Air.	With Three Times the Theoretical Supply of Air.	In Pounds of Water raised 1° per pound of Combustible.	In Pounds of Water evaporated from and at 212°, with 1 lb. Combustible.	With Chimney Draft.	With Blast, Theoretical Supply of Air at 60°, Gas 320°.
Hydrogen,	36.00	5750	3860	2860	1940	62032	64.20		
Petroleum,	15.43	5050	3515	2710	1850	21000	21.74	18.55	19.90
Carbon { Charcoal, Coke, Anthracite Coal, }	12.13	4580	3215	2440	1650	14500	15.00	13.30	14.14
Coal—Cumberland,	12.06	4900	3360	2550	1730	15370	15.90	14.28	15.06
Coal—Coking Bituminous,	11.73	5140	3520	2680	1810	15837	16.00	14.45	15.19
Coal—Cannel,	11.80	4850	3330	2540	1720	15080	15.60	14.01	14.76
Coal—Lignite,	9.30	4600	3210	2490	1670	11745	12.15	10.78	11.46
Peat—Kiln dried,	7.68	4470	3140	2420	1660	9660	10.00	8.92	9.42
Peat—Air dried, 25 per cent. water,	5.76	4000	2820	2240	1550	7000	7.25	6.41	6.78
Wood—Kiln dried,	6.00	4080	2910	2260	1530	7245	7.50	6.64	7.02
Wood—Air dried, 20 per cent. water,	4.80	3700	2607	2100	1490	5600	5.80	4.08	4.39

TABLE SHOWING APPROXIMATE CHEMICAL COMPOSITION OF SEVERAL TYPICAL KINDS OF SOLID FUELS.

	Moisture.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.
Wood, perfectly dry,	0	50	6.0	41.5	1.0	...	1.5
Wood, ordinary,	20.0	40	4.8	33.2	0.8	...	1.2
Peat,	30.0	40.6	4.2	21.7	...	...	3.5
Charcoal,	12.0	84	1.0	0	...	...	3.0
Straw,	16.0	36	5.0	38.0	...	...	5.0
Coal, Anthracite,	1.0	86	1.0	1.0	0.5	0.5	10.0
Coal, Semi-Bituminous,	1.0	84	4.2	3.4	0.8	0.6	6.0
Coal, Bituminous, Pittsburg,	1.4	75	5.0	8.0	1.0	1.6	8.0
Coal, Bituminous, Hocking Valley, O.,	7.5	67	4.8	10.0	1.2	1.5	8.0
Coal, Bituminous, Illinois,	11.0	56	5.0	11.0	1.0	3.0	13.0
Brown Coal, Pacific coast,	16.8	50	3.8	13.6	0.9	...	13.2
Lignite, Pacific coast,	14.0	55	4.0	15.0	1.0	1.0	5.0

The above tables show approximately the composition and heating value of several typical kinds of fuel. It is not possible in tables of this character to give figures that are accurate, for the reason that the composition of the different items is exceedingly variable. The tables are useful, therefore, only when fairly approximate figures are desired.

The actual heating value of a coal, as determined by test with an instrument known as a "bomb calorimeter," agrees very closely with that calculated from the analysis, usually within 2 per cent. when both the analysis and the calorimeter test are made by a skilled chemist.

The analyses given in the above table are called "ultimate analyses," since the constituents of the fuel, except the moisture and ash, are reduced to the ultimate chemical elements. Another kind of analysis, called "proximate analysis," is more commonly used, which separates the coal into four parts, viz.: moisture, volatile matter, fixed carbon, and ash. The method of making this analysis is as follows: A pulverized sample, carefully weighed, is heated to a temperature not exceeding 280° Fahr. until it is found by repeated weighings to have ceased to lose weight. The loss in weight by this heating is recorded as the moisture. The heating is then continued in a crucible covered with a lid, and gradually raised in temperature to a red heat, at which it is maintained for a few minutes, or until gas ceases to be driven off. The crucible is then cooled in a desiccator, to prevent absorption of moisture from the air, and weighed. The loss in weight by this heating is recorded as volatile matter. The crucible is then raised to a white heat, with the lid partly open, so as to admit air to burn the coal, and the heating is continued until all the carbon is burned away, leaving nothing but the ash, which after cooling is weighed, and the difference between this and the previous weight is recorded as fixed carbon. The fixed carbon being thus obtained "by difference" the sum of the four constituents will add up to 100 per cent. The analysis, when carefully made, is practically accurate as regards the moisture and ash, but the percentages of volatile matter and of fixed carbon may be a few per cent. in error, as they appear to vary with the time and temperature of heating. Sometimes a proximate analysis is reported giving the percentage of sulphur, the sum of the moisture, volatile matter, fixed carbon, sulphur, and ash adding up to 100. The sulphur is not actually determined in the proximate analysis, but a separate determination is made of it by the ordinary methods of the chemist, and one-half of it subtracted from the volatile matter and one-half from the fixed carbon, on the supposition that half of the sulphur escaped during each of the two heatings. Some chemists subtract forty per cent. of the sulphur from the volatile matter and 60 per cent. from the fixed carbon. Others report the four constituents as found by the proximate analysis, adding them up to 100, stating the sulphur separately. This seems to be the preferable method. Coals that are high in sulphur are apt to form a troublesome clinker on the grates.

The proximate analysis is of great value for indicating the general character of a coal. By dividing the percentages of volatile matter and fixed carbon each by their sum we obtain the percentages of each in the "combustible" or coal dry and free from ash. These percentages serve to identify the class to which the coal belongs, as anthracite, semi-anthracite, semi-bituminous, bituminous, or lignite, as follows:—

	Fixed Carbon per cent. of Combustible.	Volatile Matter per cent. of Combustible.
Anthracite, ...	100 to 92	0 to 8
Semi-Anthracite, ...	92 to 87	8 to 13
Semi-Bituminous, ...	87 to 75	13 to 25
Bituminous, ...	75 to 50	25 to 50
Lignite, ...	below 50	over 50

The class of coal being thus determined, the value of any coal in a class may be further judged by the percentages of moisture, ash, and sulphur.

PROXIMATE ANALYSES AND HEATING VALUES OF AMERICAN COALS.

	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Heating Value per lb. coal, heat units.	Volatile Matter per cent. of combustible.	Heating Value per lb. combustible, heat units.	Theoretical Evaporation lbs. water from and at 212° per lb. combustible
Anthracite.									
Northern coal field, ...	3.42	4.38	83.27	8.20	.73	13,160	5.00	14,900	15.42
East Middle coal field, . . .	3.71	3.08	86.40	6.22	.58	13,420	3.44	14,900	15.42
West Middle coal field, . . .	3.16	3.72	81.59	10.65	.50	12,840	4.36	14,900	15.42
Southern coal field, ...	3.09	4.28	83.81	8.18	.64	13,220	4.85	14,900	15.42
Anthracite from one mine.									
Egg, . . Screen 2½″–1¾″,	....	....	88.49	5.66	....	......	....	......	....
Stove, . Screen 1¾″–1¼″,	....	....	83.67	10.17	....	......	....	......	....
Chestnut, Screen 1¼″–¾″,	....	....	80.72	12.67	....	......	....	......	....
Pea, . . Screen ¾″–½″,	....	....	79.05	14.66	....	......	....	......	....
Buckwheat, Screen ½″–¼″,	....	....	76.92	16.62	....	......	....	......	....
Semi-Anthracite.									
Loyalsock field, ...	1.30	8.10	83.34	6.23	1.63	13,920	8.86	15,500	16.05
Bernice basin, ...	.65	9.40	83.69	5.34	.91	13,700	10.98	15,500	16.05
Semi-Bituminous.									
Broad Top, Pa., ...	.79	15.61	77.30	5.40	.90	14,820	17.60	15,800	16.36
Clearfield County, Pa., . . .	.76	22.52	71.82	3.99	.91	14,950	24.60	15,700	16.25
Cambria County, Pa., . . .	.94	19.20	71.12	7.04	1.70	14,450	22.71	15,700	16.25
Somerset County, Pa., . . .	1.58	16.42	71.51	8.62	1.87	14,200	20.37	15,800	16.36
Cumberland, Md., ...	1.09	17.30	73.12	7.75	.74	14,400	19.79	15,800	16.36
Pocahontas, Va., ...	1.00	21.00	74.39	3.03	.58	15,070	22.50	15,700	16.25
New River, W. Va., ...	.85	17.88	77.64	3.36	.27	15,220	18.95	15,800	16.36
Bituminous.									
Connellsville, Pa., ...	1.26	30.12	59.61	8.23	.78	14,050	34.03	15,300	15.84
Youghiogheny, Pa., ...	1.03	36.50	59.05	2.61	.81	14,450	38.73	15,000	15.53
Pittsburg, Pa., ...	1.37	35.90	52.21	8.02	1.80	13,410	41.61	14,800	15.32
Jefferson County, Pa., . . .	1.21	32.53	60.99	4.27	1.00	14,370	35.47	15,200	15.74
Middle Kittanning seam, Pa., .	1.81	35.33	53.70	7.18	1.98	13,200	40.27	14,500	15.01
Upper Freeport seam, Pa. and O.	1.93	35.90	50.19	9.10	2.89	13,170	43.59	14,800	15.32
Thacker, W. Va., ...	1.38	35.04	56.03	6.27	1.28	14,040	39.33	15,200	15.74
Jackson County, O., ...	3.83	32.07	57.60	6.50	....	13,090	35.76	14,600	15.11
Brier Hill, O., ...	4.80	34.60	56.30	4.30	....	13,010	38.20	14,300	14.80
Hocking Valley, O., . .	6.59	34.97	48.85	8.00	1.59	12,130	42.81	14,200	14.70
Vanderpool, Ky., ...	4.00	34.10	54.60	7.30	....	12,770	38.50	14,400	14.91
Muhlenberg County, Ky., . .	4.33	33.65	55.50	4.95	1.57	13,060	38.86	14,400(?)	14.91
Scott County, Tenn., ...	1.26	35.76	53.14	8.02	1.80	13,700	34.17	15,100(?)	15.63
Jefferson County, Ala., . . .	1.55	34.44	59.77	2.62	1.42	13,770	37.63	14,400(?)	14.91
Big Muddy, Ill., ...	7.50	30.70	53.80	8.00	....	12,420	36.30	14,700	15.22
Mt. Olive, Ill., ...	11.00	35.65	37.10	13.00	....	10,490	47.00	13,800	14.29
Streator, Ill., ...	12.00	33.30	40.70	14.00	....	10,580	45.00	14,300	14.80
Missouri, ...	6.44	37.57	47.94	8.05	....	12,230	43.94	14,300(?)	14.80
Lignites and Lignitic Coals.									
Iowa, ...	8.45	37.09	35.60	18.86	....	8,720	51.03	12,000(?)	12.42
Wyoming, ...	8.19	38.72	41.83	11.26	....	10,390	48.07	12,900(?)	13.35
Utah, ...	9.29	41.97	44.37	3.20	1.18	11,030	48.60	12,600(?)	13.04
Oregon Lignite, ...	15.25	42.98	33.32	7.11	1.66	8,540	54.95	11,000(?)	11.39

The preceding table gives the proximate analyses and the heating values of a number of American coals. The analyses are selected from various sources and in general give average values of many samples. The heating values per pound of combustible are either obtained from calorimetric determinations or by calculation from ultimate analyses, except those marked (?), which are estimated from the heating values of coals of similar composition. The theoretical evaporation, in the last column, is obtained by dividing the heating value per pound of combustible by 965.7, the number of heat units required to evaporate a pound of water at 212° into steam of the same temperature. The heating values per pound of combustible given in the table, except those marked (?) are probably within 3 per cent. of the average actual heating values of the combustible portion of the coals of the several districts, the combustible being defined as the coal minus its moisture and ash. When the percentage of moisture and ash in any given lot of coal is known the heating value per pound of coal may be found by multiplying the heating value per pound of combustible by the difference between 100 per cent. and the sum of the percentages of moisture and ash. The figures in the column headed "Heating value per lb. coal" are calculated in this manner.

Tables giving the heating values per pound of coal (not combustible) are usually of little value, for published analyses are often of selected samples, containing less moisture and ash than the average of the coal mined, and the ash is apt to vary greatly in different portions of a mine. The combustible portion of the coal from any given mine, seam, or district, however, especially if it contains over 60 per cent. of fixed carbon, is usually very constant in heating value.

An inspection of the above table reveals many interesting facts. The semi-bituminous coals of Pennsylvania, Maryland, Virginia, and West Virginia have the highest heating value per pound of combustible of any coals in the United States, and are remarkably uniform, the whole range of their heating value per pound of combustible probably being within the limits of 15,500 and 16,000 heat units. They are also very low in moisture, ash, and sulphur, so that they are exceptionally valuable as steam coals.

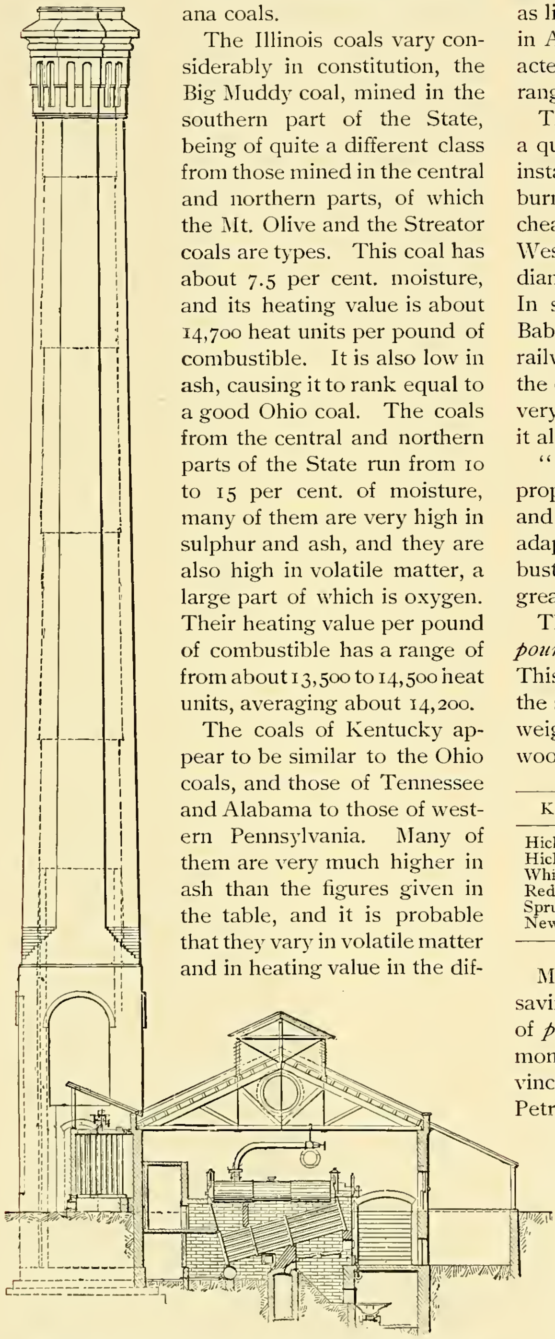
The anthracites are about 6 per cent. lower in heating value per pound of combustible, due to their being low in hydrogen. The ash is usually much higher than the figures given in the table. The figures for moisture given in the table seem rather high, other analyses reporting as low as one per cent., but in pea and buckwheat coals it will in winter time sometimes run as high as 7 per cent., being chiefly surface moisture contained between the particles of coal, and not inclosed in the coal itself. The semi-anthracites are mined in a limited extent of territory in Pennsylvania. Their heating value is between that of the anthracites and the semi-bituminous coals.

There is a marked dividing line between the semi-bituminous and the bituminous coals in the United States, few coals being known, except in the South and in Colorado, which are on the dividing line between these two classes, or containing between 25 and 30 per cent. of volatile matter in the combustible. The bituminous coals are of great variety. We have first the coals mined in Fayette, Westmoreland, Indiana, and Jefferson counties in Pennsylvania, including the Connellsville and the Youghiogheny coals, lying just west of the semi-bituminous region, which includes Somerset, Cambria, and Clearfield counties. These coals are low in moisture and sulphur, moderately low in ash, and their heating value usually ranges between 15,000 and 15,300 heat units per pound of combustible. The Thacker, W. Va., coal is also of this class. Next come the coals of the western tier of counties in Pennsylvania, belonging to the Pittsburg, Upper Freeport, and Middle Kittanning seams, which have a heating value between 14,200 and 15,000 heat units per pound of combustible. These coals are also low in moisture, but some of them are rather high in sulphur.

Passing further west we have the Ohio coals, characterized by higher percentages of moisture than the Pennsylvania coals, and higher oxygen as shown by the ultimate analysis. Their heating value ranges from 14,200 to 14,600 heat units per pound of combustible. The Vanderpool, Ky., coal, given in the table, also appears to belong to this class. The three Ohio coals given in the table have from 3.83 to 6.59 per cent. moisture, and it is to be noted that this is not surface moisture but that found in a lump of apparently dry coal. All of the bituminous coals contain moisture in the same way that wood contains it, and they are hygroscopic, that is, if dried in an oven they will afterwards absorb moisture from the atmosphere. The chief difference in the character of different Western bituminous coals is in the amount of moisture that they contain, some of the Illinois coals containing as high as 15 per cent., which may be driven off by heating them to 240° to 280° Fahr., but they will absorb all of this moisture again on prolonged exposure to the air. The Indiana coals contain much more moisture than the Ohio coals, but less than the Illinois coals. The sample whose analysis is given in the table is about an average of the Indiana coals.

The Illinois coals vary considerably in constitution, the Big Muddy coal, mined in the southern part of the State, being of quite a different class from those mined in the central and northern parts, of which the Mt. Olive and the Streator coals are types. This coal has about 7.5 per cent. moisture, and its heating value is about 14,700 heat units per pound of combustible. It is also low in ash, causing it to rank equal to a good Ohio coal. The coals from the central and northern parts of the State run from 10 to 15 per cent. of moisture, many of them are very high in sulphur and ash, and they are also high in volatile matter, a large part of which is oxygen. Their heating value per pound of combustible has a range of from about 13,500 to 14,500 heat units, averaging about 14,200.

The coals of Kentucky appear to be similar to the Ohio coals, and those of Tennessee and Alabama to those of western Pennsylvania. Many of them are very much higher in ash than the figures given in the table, and it is probable that they vary in volatile matter and in heating value in the different districts within the range of the various coals of western Pennsylvania and Ohio.



Boiler House and Chimney for Babcock & Wilcox Boilers, 2000 H.P., with Artificial Blast, Economizer, etc.

West of the Mississippi the coals are generally very high in moisture and ash, and their volatile matter is high in oxygen, characterizing them as lignites, but there are exceptions to this rule in Arkansas and Colorado, in which the character of the coals varies through the whole range between anthracite and lignite.

The relative value of different fuels is largely a question of locality and transportation. For instance, in some parts of Central America they burn rosewood under their boilers, because it is cheaper than coal; while a few years ago in the West it was found, during a coal famine, that Indian corn was the cheapest fuel they could burn. In some places they burn manure only. The Babcock & Wilcox boilers of Chicago cable railways were for a long time run regularly on the offal from the stables of the horse roads, a very small proportion of coal being used to keep it alight.

"Slack," or the screenings from coal, when properly mixed,—anthracite and bituminous,—and burned by means of a blower on a grate adapted to it, is nearly equal in value of combustible to coal, but its percentage of refuse is greater.

The effective value of all kinds of wood *per pound*, when dry, is substantially the same. This is usually estimated at 0.4 the value of the same weight of coal. The following are the weights and comparative value of different woods by the cord:—

Kind of Wood.	Weight.	Kind of Wood.	Weight.
Hickory, Shellbark	4469	Beech	3126
Hickory, Red heart	3705	Hard Maple . . .	2878
White Oak . . .	3821	Southern Pine . .	3375
Red Oak	3254	Virginia Pine . .	2680
Spruce	2325	Yellow Pine . . .	1904
New Jersey Pine .	2137	White Pine . . .	1868

Much was said at one time about the wonderful saving which could be expected from the use of *petroleum for fuel.* This is all a myth, and a moment's attention to facts is sufficient to convince anyone that no such possibility exists. Petroleum has a heating capacity, when fully burned, equal to from 21,000 to 22,000 B.T.U. per pound, or say 50 per cent. more than coal. But, owing to the ability to burn it with less losses, it has been found through extended experiments by the pipe lines that under the same boilers, and doing the same work, a pound of petroleum is equal to 1.8 pounds of coal. The experiments on locomotives in Russia have shown practically the same value, or 1.77. Now, a gallon of petroleum weighs 6.7 pounds (though the standard buying and selling weight is 6.5 pounds), and therefore an actual gallon of petroleum is equivalent under a boiler to twelve pounds of coal, and 190 standard gallons are equal to a gross ton of coal. It is very easy with these data to determine the relative cost. At the wells, if the oil is worth say two cents a gallon, the cost is equivalent to $3.80 per ton for coal at the same place, while at say three cents per gallon, the lowest price at which it can be delivered in the vicinity of New York, it costs the same as coal at $5.70 per ton. The Standard Oil Co. estimate that 173 gallons are equal to a gross ton of coal, allowing for incidental savings, as in grate bars, carting ashes, attendance, etc.

Sawdust can be utilized for fuel to good advantage by a special furnace and automatic feeding devices. Spent tan bark is also used, mixed with some coal, or it may be burned without the coal in a proper furnace. Its value is about one-fourth that of the same weight of wood, as it comes from the press, but when dried its value is about 85 per cent. of the same weight of wood in same state of dryness.

Bagasse, the refuse of sugar cane, after being dried in the sun, is largely employed in Cuba. Its value is about equal to the same weight of pine wood, in the same state of dryness. As it comes from the mill it contains from 50 to 80 per cent. of water, in which state it may be burned in Cook's Bagasse Furnace, under Babcock & Wilcox Boilers, with a result nearly or quite equal to that of the dried bagasse under ordinary boilers, thus saving the large expense of drying it.

It has been estimated that on an average one pound of coal is equal, for steam-making purposes, to 2 pounds dry peat, 2¼ to 2½ pounds dry wood, 2½ to 3 pounds dried tan bark, 2½ to 3 pounds sun-dried bagasse, 2¾ to 3 pounds cotton stalks, 3¼ to 3¾ pounds wheat or barley straw, 5 to 6 pounds wet bagasse, and 6 to 8 pounds wet tan bark.

Natural gas varies in quality, but is usually worth 2 to 2½ times the same *weight* of coal, or about 30,000 cubic feet are equal to a ton of coal.

TEMPERATURE OF FIRE.

By reference to the table of combustibles, it will be seen that the temperature of the fire is nearly the same for all kinds of combustibles, under similar conditions. If the temperature is known, the conditions of combustion may be inferred. The following table, from M. Pouillet, will enable the temperature to be judged by the appearance of the fire:—

Appearance.	Temp. Fah.	Appearance.	Temp. Fah.
Red, just visible,	977°	Orange, deep,	2010°
" dull, . . .	1290	" clear,	2190
" Cherry, dull,	1470	White heat, .	2370
" " full,	1650	" bright,	2550
" " clear,	1830	" dazzling,	2730

To determine temperature by fusion of metals, etc.:—

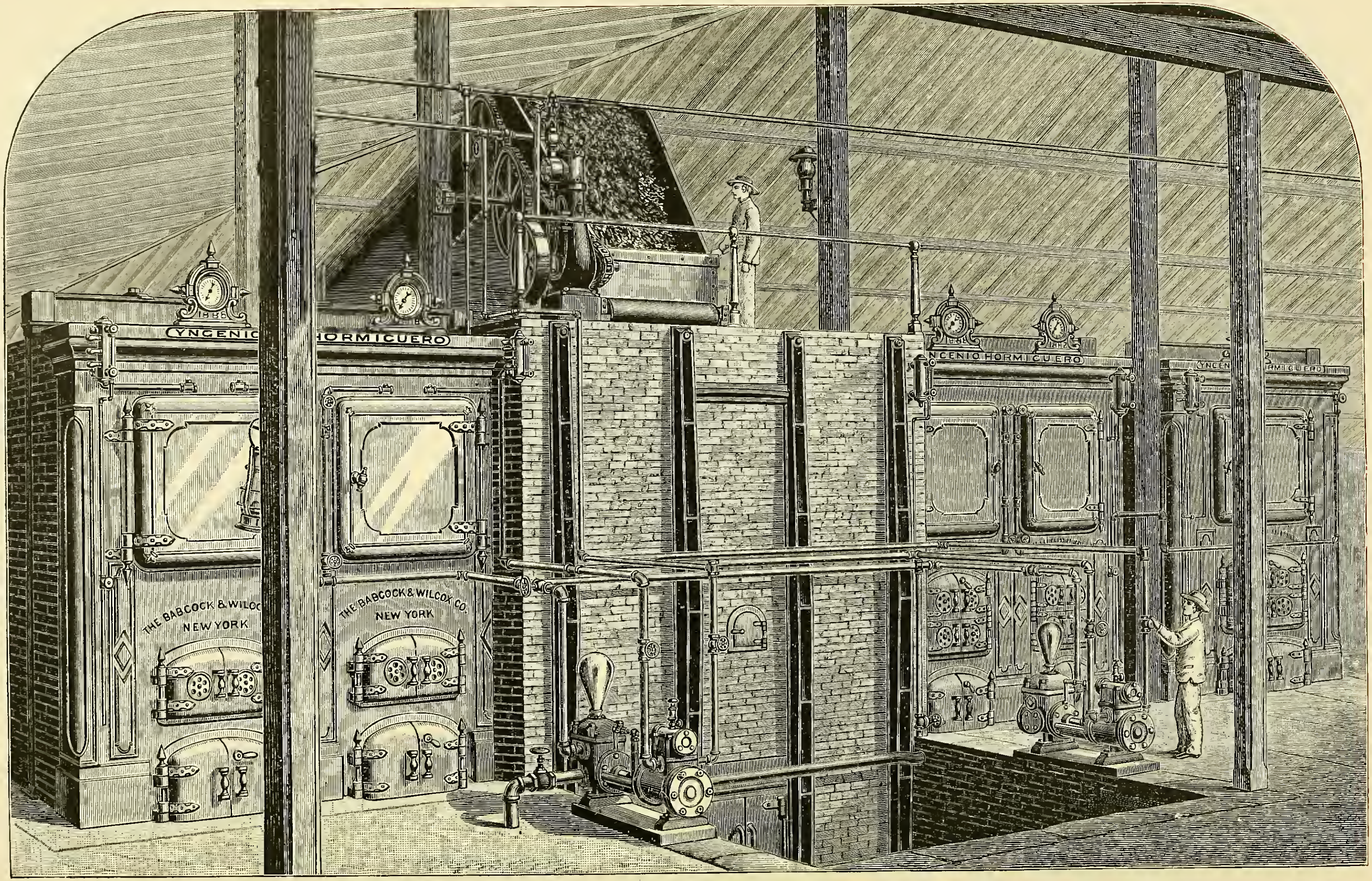
Substance.	Temp. Fah.	Metal.	Temp. Fah.	Appearance.	Temp. Fah.
Spermaceti,	120°	Lead, .	610°	Silver, pure,	1830°
Wax, white,	154	Zinc, .	700	Gold Coin, .	2156
Sulphur, .	239	Antimony,	810	Iron Cast, med	2010
Tin, . .	455	Aluminum,	1160	Steel, . . .	2550
Bismuth,	518	Brass, .	1650	Wrought Iron,	2910

CONDENSERS.

The condensation of steam in a separate chamber from the engine cylinder instead of by a spray of water injected into the cylinder itself after the steam piston had completed its stroke, was an invention of James Watt, in 1765, for which he received letters patent in 1769. It was the first step in the history of the steam engine in the direction of increased efficiency from the atmospheric engines in use at that time, towards the present era of high steam pressure and multiple expansion condensing engines.

Where a sufficient quantity of water suitable for boiler feeding purposes is available, the jet condenser, being the simplest and easiest to operate, is preferable. Where, however, water suitable for boiler feeding is not available, a surface condenser may be used. In this type the steam is condensed in a condensing chamber on the surface of tubes through which cold water is circulating, and the distilled water so furnished may be again fed to the boilers. Where any considerable amount of cylinder oil is used, some provision must be made with surface condensers to remove this oil before the water is fed to the boilers. With either type the quantity of water to be circulated through the condenser should be from 20 to 40 times the quantity of steam to be condensed, depending upon the temperature of the water available for condensing purposes.

American condenser manufacturers have recently introduced several types of self-cooling condensers by which the hot water delivered from the condenser pumps can be cooled and reused, so that with water sufficient in quantity for boiler feed purposes only, the plant may be located at any convenient point, and still retain the fuel saving and other benefits of high steam pressures and condensers.



Babcock & Wilcox Boilers, with Cook's Automatic Apparatus for Burning Green Bagasse, at Yngenio Central Hormiguero, Cuba.

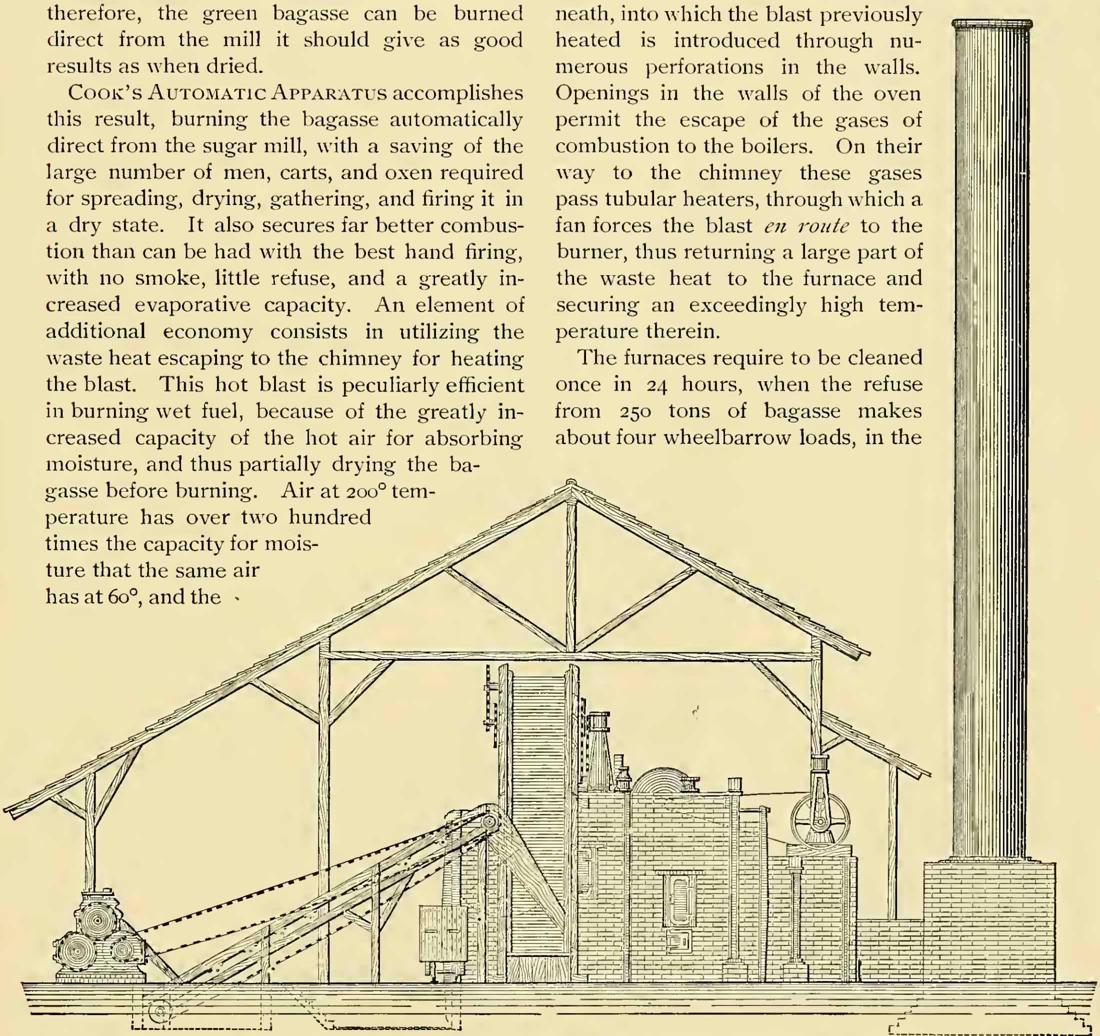
BURNING GREEN BAGASSE

The refuse from sugar cane, after it has left the grinding rolls, contains usually from 25 to 40 per cent. of woody fiber and from 6 to 9 per cent. ot sugar, while the balance, respectively 66 to 54 per cent., is water. In this condition it is not combustible in ordinary furnaces, for which purpose it requires to be sun-dried, which process removes from eight to nine tenths of the moisture and nearly all the sugar through fermentation. This sugar itself is an excellent fuel, and if it could be utilized as such would be nearly sufficient to evaporate the water in which it is dissolved, so that it is probable that the process of drying by natural means destroys more fuel than sufficient to do the drying including that wasted in the several handlings. If, therefore, the green bagasse can be burned direct from the mill it should give as good results as when dried.

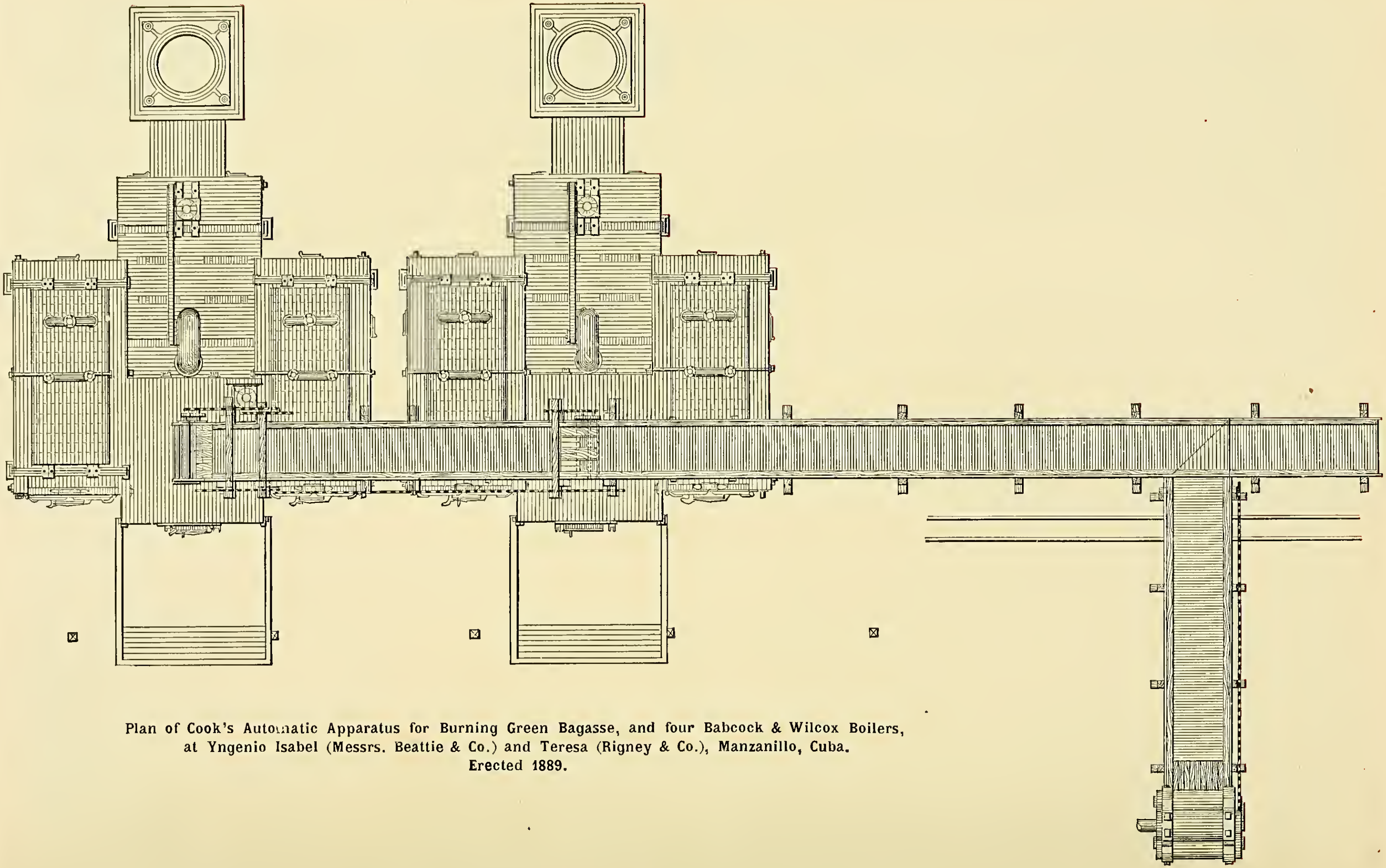
Cook's Automatic Apparatus accomplishes this result, burning the bagasse automatically direct from the sugar mill, with a saving of the large number of men, carts, and oxen required for spreading, drying, gathering, and firing it in a dry state. It also secures far better combustion than can be had with the best hand firing, with no smoke, little refuse, and a greatly increased evaporative capacity. An element of additional economy consists in utilizing the waste heat escaping to the chimney for heating the blast. This hot blast is peculiarly efficient in burning wet fuel, because of the greatly increased capacity of the hot air for absorbing moisture, and thus partially drying the bagasse before burning. Air at 200° temperature has over two hundred times the capacity for moisture that the same air has at 60°, and the air required for the combustion of the fuel in the bagasse, if forced into the furnace at 300° temperature, will carry away the excess of moisture in the fuel without other heat than that itself contains. Therefore, if the blast is heated by the waste gases to that temperature, it secures the full value of the fuel for steam making, the same as if it were dried before it was delivered to the furnace. These considerations explain the fact that where these burners have been erected they have always brought about a large reduction in the supplementary fuel required with dry bagasse, besides giving more and steadier steam pressure. In a well arranged plantation the bagasse is sufficient without other fuel.

The furnace of Cook's apparatus consists in an oven of brick having a smaller chamber beneath, into which the blast previously heated is introduced through numerous perforations in the walls. Openings in the walls of the oven permit the escape of the gases of combustion to the boilers. On their way to the chimney these gases pass tubular heaters, through which a fan forces the blast *en route* to the burner, thus returning a large part of the waste heat to the furnace and securing an exceedingly high temperature therein.

The furnaces require to be cleaned once in 24 hours, when the refuse from 250 tons of bagasse makes about four wheelbarrow loads, in the



Side View of Cook's Automatic Apparatus for Burning Green Bagasse with Babcock & Wilcox Boilers, at Yngenio Senado.



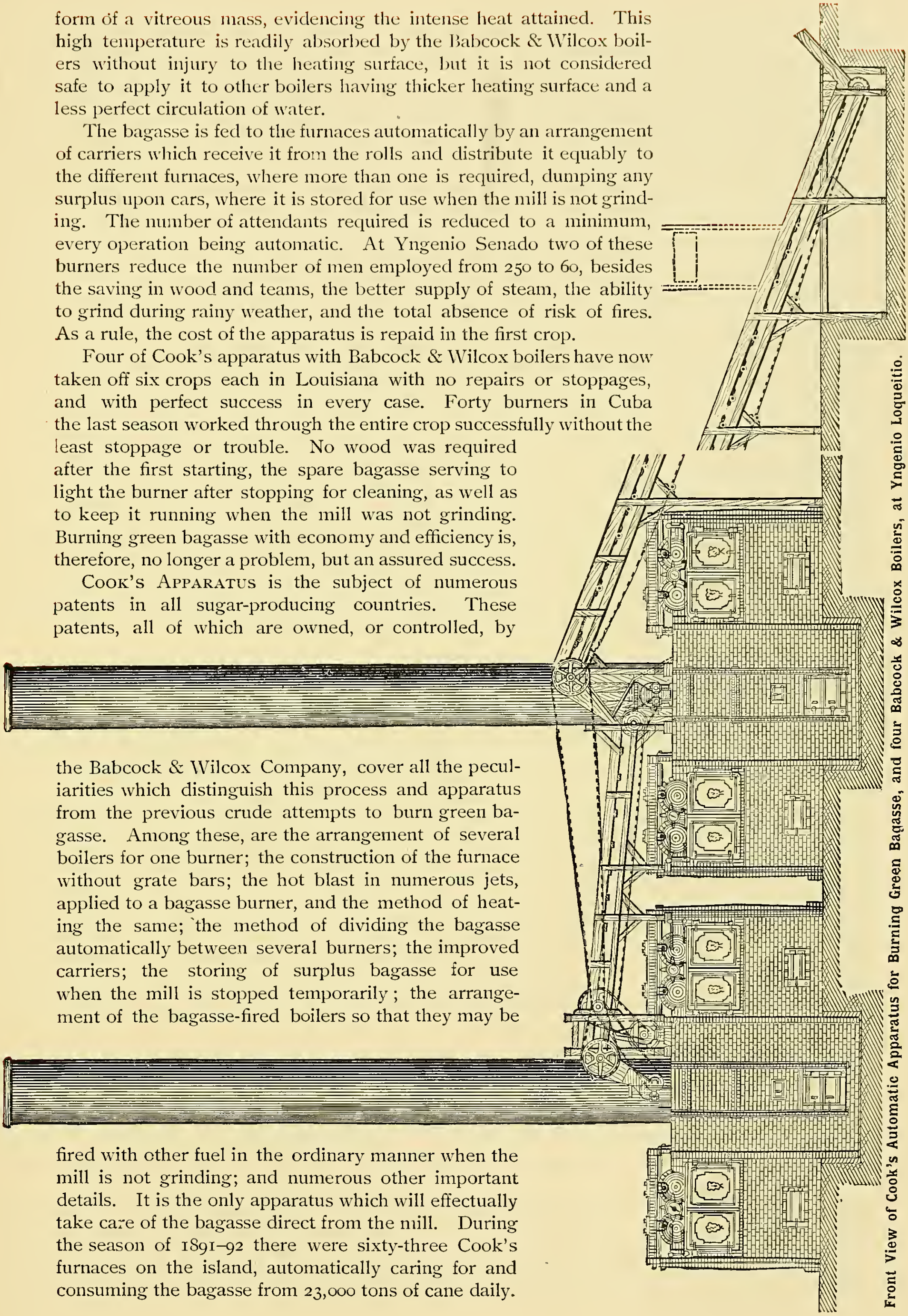
Plan of Cook's Automatic Apparatus for Burning Green Bagasse, and four Babcock & Wilcox Boilers, at Yngenio Isabel (Messrs. Beattie & Co.) and Teresa (Rigney & Co.), Manzanillo, Cuba. Erected 1889.

form of a vitreous mass, evidencing the intense heat attained. This high temperature is readily absorbed by the Babcock & Wilcox boilers without injury to the heating surface, but it is not considered safe to apply it to other boilers having thicker heating surface and a less perfect circulation of water.

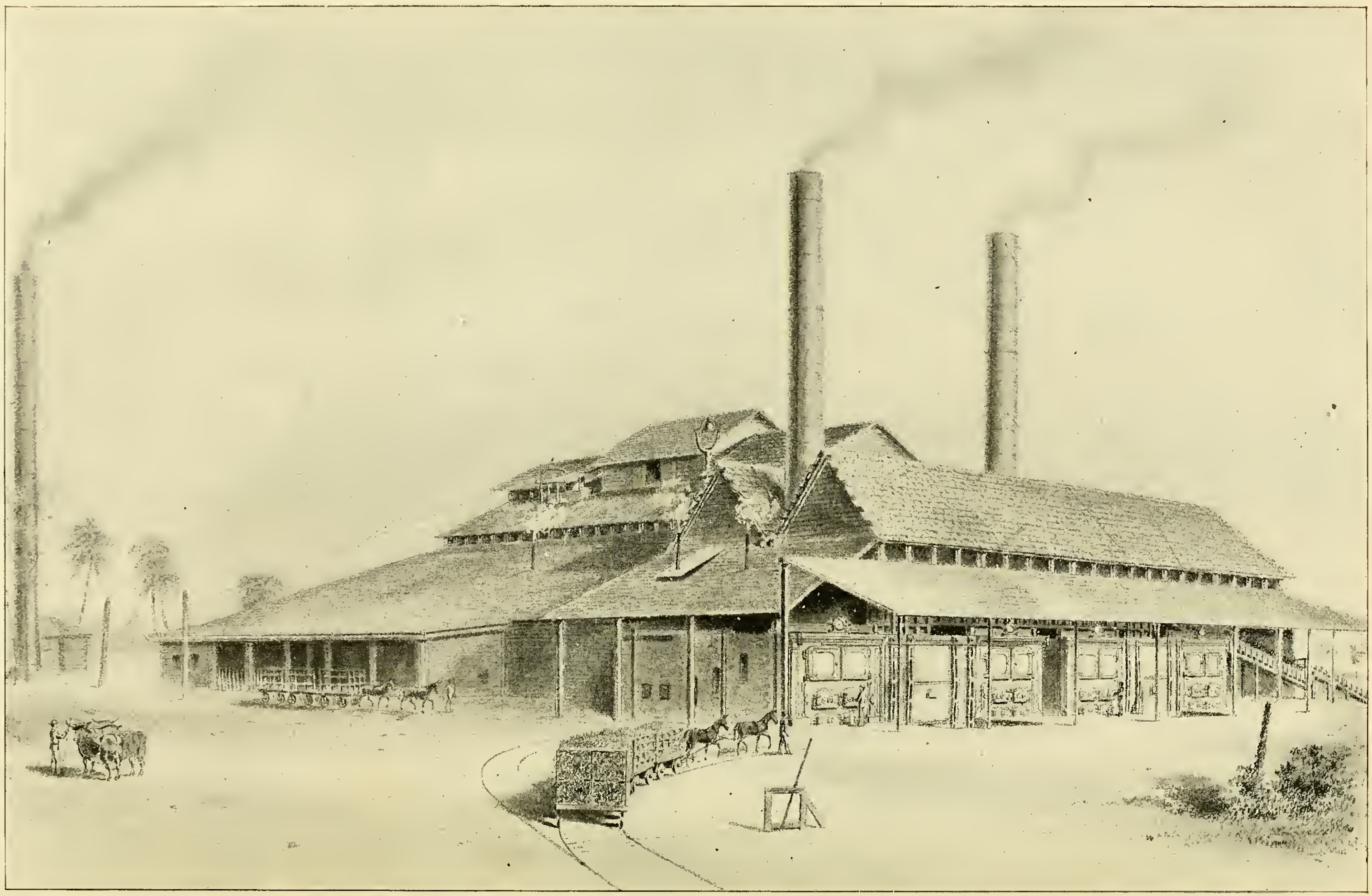
The bagasse is fed to the furnaces automatically by an arrangement of carriers which receive it from the rolls and distribute it equably to the different furnaces, where more than one is required, dumping any surplus upon cars, where it is stored for use when the mill is not grinding. The number of attendants required is reduced to a minimum, every operation being automatic. At Yngenio Senado two of these burners reduce the number of men employed from 250 to 60, besides the saving in wood and teams, the better supply of steam, the ability to grind during rainy weather, and the total absence of risk of fires. As a rule, the cost of the apparatus is repaid in the first crop.

Four of Cook's apparatus with Babcock & Wilcox boilers have now taken off six crops each in Louisiana with no repairs or stoppages, and with perfect success in every case. Forty burners in Cuba the last season worked through the entire crop successfully without the least stoppage or trouble. No wood was required after the first starting, the spare bagasse serving to light the burner after stopping for cleaning, as well as to keep it running when the mill was not grinding. Burning green bagasse with economy and efficiency is, therefore, no longer a problem, but an assured success.

Cook's Apparatus is the subject of numerous patents in all sugar-producing countries. These patents, all of which are owned, or controlled, by the Babcock & Wilcox Company, cover all the peculiarities which distinguish this process and apparatus from the previous crude attempts to burn green bagasse. Among these, are the arrangement of several boilers for one burner; the construction of the furnace without grate bars; the hot blast in numerous jets, applied to a bagasse burner, and the method of heating the same; the method of dividing the bagasse automatically between several burners; the improved carriers; the storing of surplus bagasse for use when the mill is stopped temporarily; the arrangement of the bagasse-fired boilers so that they may be fired with other fuel in the ordinary manner when the mill is not grinding; and numerous other important details. It is the only apparatus which will effectually take care of the bagasse direct from the mill. During the season of 1891–92 there were sixty-three Cook's furnaces on the island, automatically caring for and consuming the bagasse from 23,000 tons of cane daily.



Front View of Cook's Automatic Apparatus for Burning Green Bagasse, and four Babcock & Wilcox Boilers, at Yngenio Loqueitio.



Babcock & Wilcox Boilers, with Cook's Automatic Apparatus for Burning Green Bagasse, at Yngenio Central Senado. 1,000 H.P. erected 1888.

HORSE-POWER OF BOILERS.

Strictly speaking, there is no such thing as "horse-power" to a steam boiler; it is a measure applicable only to dynamic effect. But as boilers are necessary to drive steam engines, the same measure applied to steam engines has come to be universally applied to the boiler, and cannot well be discarded. In consequence, however, of the different quantity of steam necessary to produce a horse-power, with different engines, there has been great need of an accepted standard by which the amount of boiler required to provide steam for a commercial horse-power may be determined.

This standard, as fixed by Watt, was one cubic foot of water evaporated per hour from 212° for each horse-power. This was, at that time, the requirement of the best engine in use. At the present time, Professor Thurston estimates, that the water required per hour, per horse-power, in good engines, is equal to the constant 200, divided by the square root of the pressure, and that in the best engines this constant is as low as 150. This would give for good engines, working with 64 lbs. pressure, 25 lbs. water, and for the best engines working with 100 lbs., only 15 lbs. water per hourly horse-power.

The extensive series of experiments, made under the direction of C. E. Emery, M.E., at the Novelty Works, in 1866-8, and published by Professor Trowbridge, show, that at ordinary pressures, and with good proportions, non-condensing engines of from 20 to 300 H.P. required only from 25 to 30 lbs. water per hourly horse-power, in regular practice.

The standard, therefore, adopted by the judges at the late Centennial Exhibition, of 30 lbs. water per hour, evaporated, at 70 lbs. pressure, from 100°, for each horse-power, is a fair one for both boilers and engines, and has been favorably received by the Am. Soc. of Mech. Engineers and by steam users, but as the same boiler may be made to do more or less work with less or greater economy, it should be also required that the rating of a boiler be based on the amount of water it will evaporate at a high economical rate.

For purposes of economy the amount of heating surface should never be less than one, and generally not more than two, square feet, for each 5,000 British thermal units to be absorbed per hour, though this depends somewhat on the character and location of such surface. The range given above is believed to be sufficient to allow for the different conditions in practice, though a far greater range is frequently employed. As, for instance, in torpedo boats, where everything is sacrificed to lightness and power, the heating surface is sometimes made to absorb 12,000 to 15,000 B.T.U. per square foot per hour, while in some mills, where the proprietor and his advisers have gone on the principle that "too much is just enough," a square foot is only required to absorb 1000 units or less per hour. Neither extreme is good economy.

Square feet of heating surface is no criterion as between different styles of boilers—a square foot under some circumstances being many times as efficient as in others; but when an average rate of evaporation per square foot for any given boiler has been fixed upon by experiment, there is no more convenient way of rating the power of others of the same style. The following table gives an approximate list of square feet of heating surface per H.P. in different styles of boilers, and various other data for comparison:—

Type of Boiler.	Square feet of Heating Surface for One H.P.	Coal per sq. ft. H.S. per hour.	Relative Economy.	Relative Rapidity of Steaming.	Authority.
Water-tube, . .	10 to 12	.3	1.00	1.00	Isherwood.
Tubular, . . .	14 to 18	.25	.91	.50	"
Flue, ...	8 to 12	.4	.79	.25	Prof. Trowbridge.
Plain Cylinder, .	6 to 10	.5	.69	.20	
Locomotive, . .	12 to 16	.275	.85	.55	
Vertical Tubular,	15 to 20	.25	.80	.60	

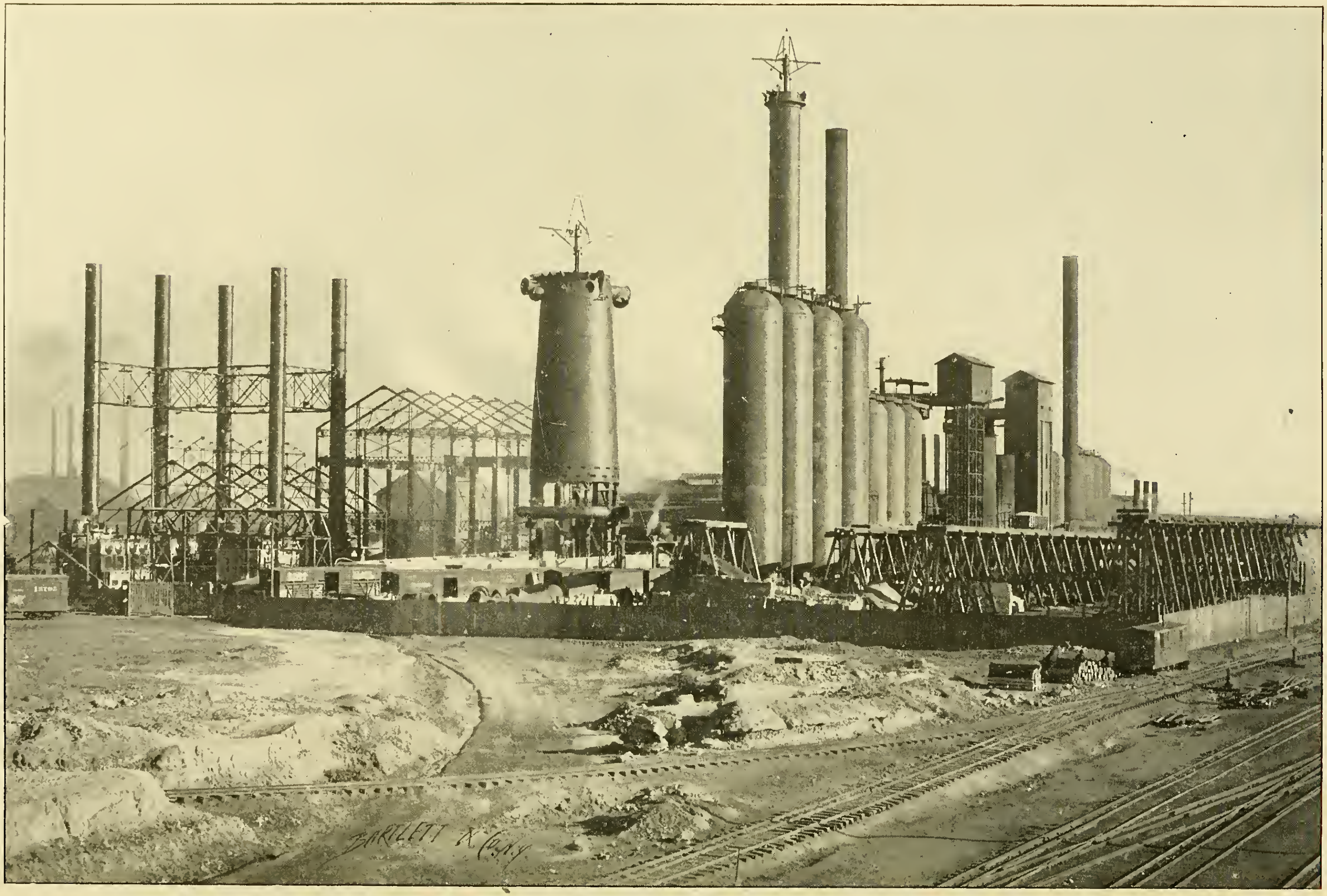
A horse-power in a steam engine or other prime mover is 550 lbs. raised 1 foot per second, or 33,000 lbs. 1 foot per minute.

HORSE-POWER OF DIFFERENT NATIONS.

Most nations have a standard for power similar to, and generally derived from, Watt's "horse-power," but, owing to different standards of weights and measures, these are not identical, though the greatest differences amount to less than 1½ per cent. The following table gives the standard horse-power for each nation, in *kilogrammeters per second*, and in *foot-pounds per second*, expressed in the foot and pound standard in each country:—

TABLE OF STANDARD HORSE-POWER FOR DIFFERENT NATIONS.

Country.	Kilogrammeters, per sec.	Baden Ft. pounds, per sec.	Saxon Ft. pounds, per sec.	Wurtemberg Ft. pounds, per sec.	Prussian Ft. pounds, per sec.	Hanoverian Ft. pounds, per sec.	English Ft. pounds, per sec.	Austrian Ft. pounds, per sec.
France and Baden,	**75**	**500**	529.68	521.58	477.93	513.53	542.47	423.68
Saxony, . .	75.045	500.30	**530**	523.89	478.22	513.84	542.80	423.93
Wurtemberg,	75.240	501.36	531.12	**525**	479.23	514.92	543.95	424.83
Prussia, . .	75.325	502.17	531.97	525.85	**480**	515.75	544.82	425.51
Hanover, .	75.361	502.41	532.23	526.10	480.23	**516**	545.08	425.72
England, .	76.041	506.94	537.03	530.84	484.56	520.65	**550**	429.56
Austria, . .	76.119	507.46	437.58	531.39	485.06	521.19	550.57	**430**

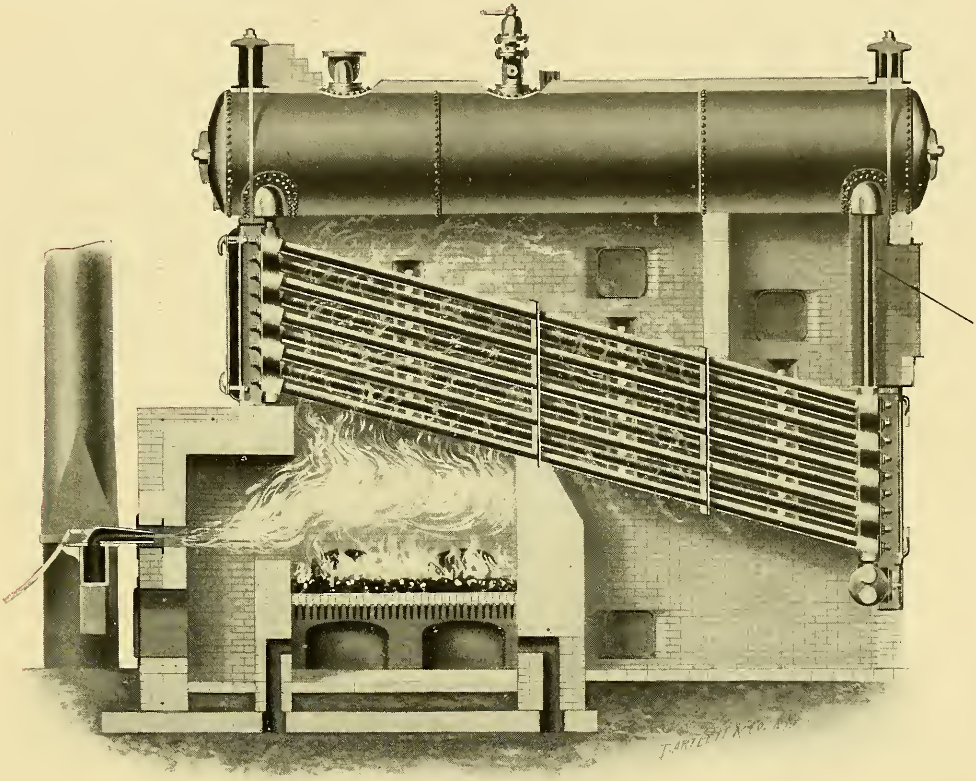


Colorado Fuel and Iron Co., Pueblo, Colo. Blast Furnace "A," Rail Mill and Power Plant. 7800 H. P. Babcock & Wilcox Boilers in use by this Company.

BOILERS IN IRON AND STEEL WORKS.

The requirements of a steam boiler in an iron or steel works are more severe than in any other establishment, with possibly the exception of a sugar plantation. The heat applied to the boiler is not only intense, but fluctuating. The utmost possible amount of work may be required from the boiler for one hour, and scarcely any work the next, while in many iron works too little attention is paid to the boiler-house by the management, it being left to the care or neglect of

This boiler possesses for this purpose the advantages of safety and economy. The intense heat of the gases from a puddling furnace is very destructive of thick plates and riveted joints, causing frequent violent explosions in boilers so heated. The thin tubes, and rapid circulation, in these boilers render them less liable to damage from the high temperature, and the arrangement of heating surface secures a fuller absorption of the waste heat. Should a tube burn out, no serious explosion can occur.

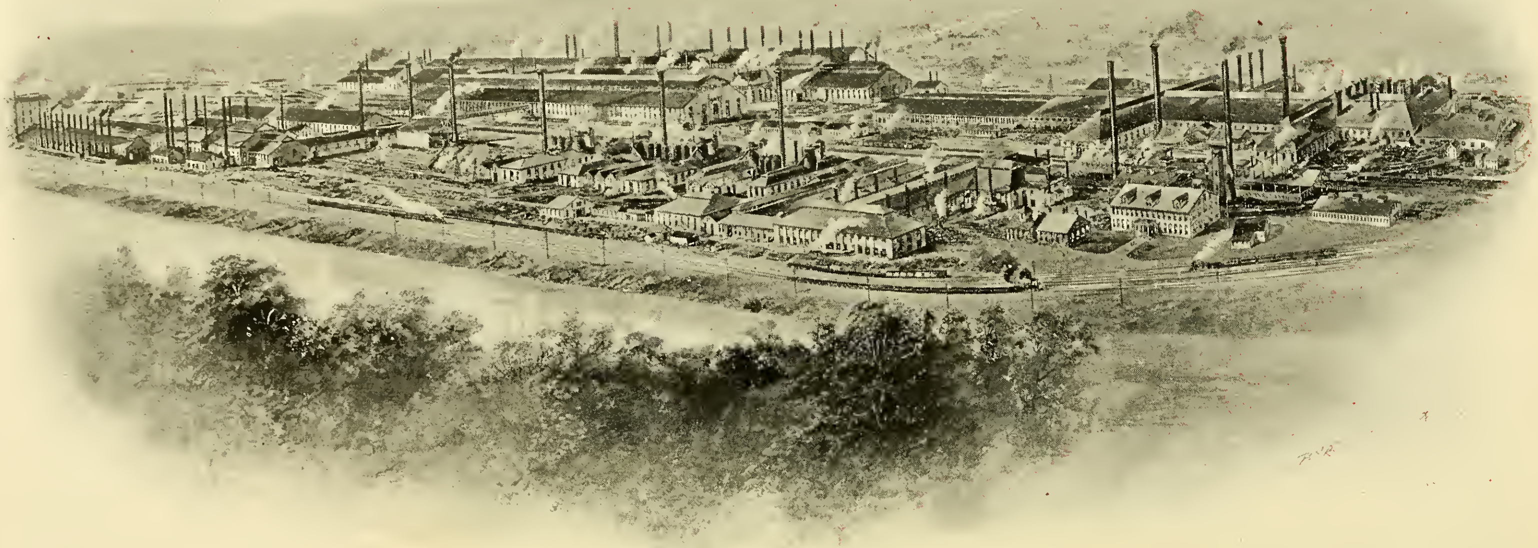


Section of Babcock & Wilcox Boiler fitted with Kennedy Burner for burning Blast Furnace Gas.

incompetent men. There is, also, frequently a lack of sufficient boiler capacity, and in consequence the boilers are driven at a rate which is both wasteful of fuel and destructive to heating surfaces.

An extended experience with the Babcock & Wilcox boilers in iron and steel works extending over many years, under a variety of conditions, in connection with heating, puddling, and blast furnaces, utilizing the waste heat, has shown their adaptability and superiority for such work.

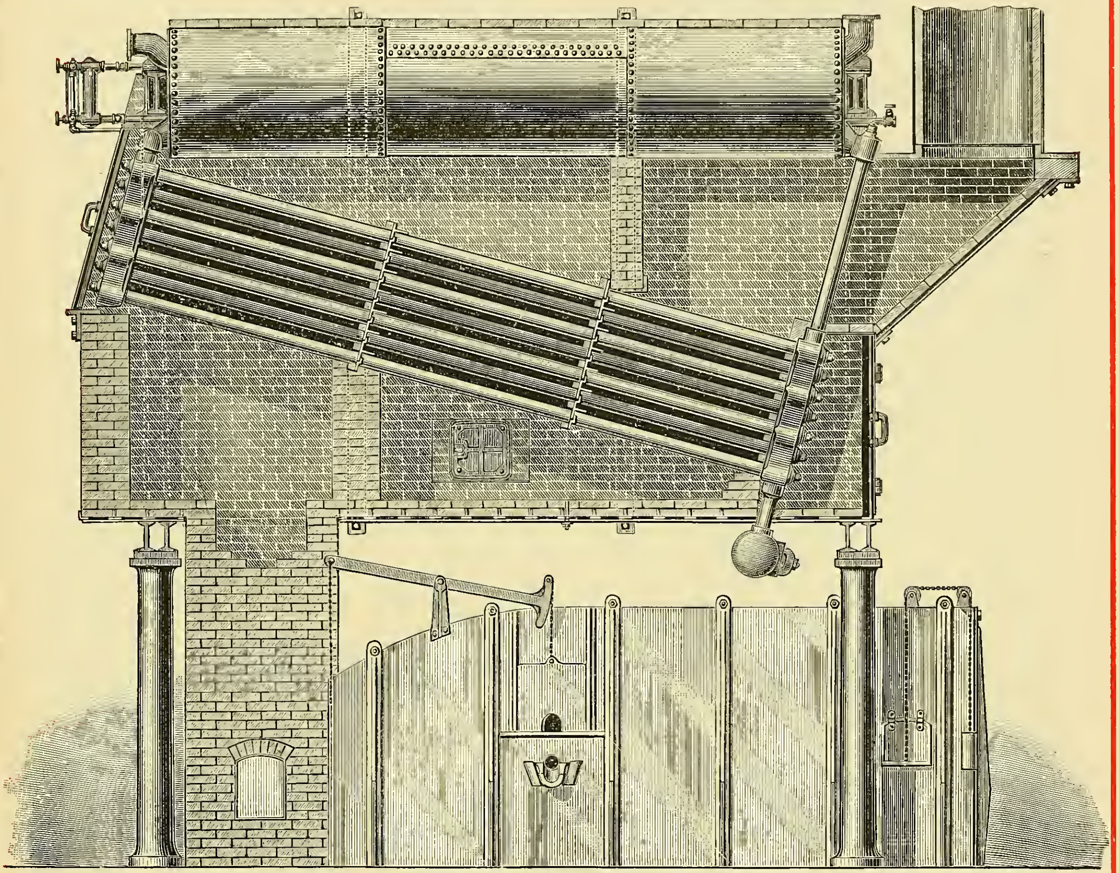
Some establishments place their boilers over the furnaces, as shown in the cut, while others place them at the side of the furnace, or in the rear. One advantage of this boiler, especially for double puddling and large heating furnaces, is that a much larger amount of heating surface can be placed over a furnace than can be done with the boilers ordinarily used for this purpose, thereby giving greater economy of fuel with less cost of erection. At the Carron Iron Works, near Glasgow, Scotland, the Lucy Furnaces,



Works of the Bethlehem Steel Company, using 11,000 H. P. Babcock & Wilcox Boilers. Erected 1896-1901

Pittsburgh, Pa., and elsewhere, these boilers are fired with the waste gases of the blast furnaces with marked success. The combustion of the gas is perfect; the boilers develop much more than their rated capacity; and the dust contained in the gas has given no trouble. The manager of the Lucy Furnaces says: —

"They are very free steamers, easily cleaned, and will do a given amount of work on very much less gas than our cylinder or two-flue boilers. They have cost nothing for repairs."



Babcock & Wilcox Boilers over Puddling Furnace.

In rolling mills doing the heaviest and most irregular kind of work, the success of these boilers has been equally encouraging, and, in a number of the Bessemer Steel Works, they are supplying steam to reversing engines rolling steel ingots in two high trains, while several large plants supply power for rolling rods, bar iron, rails and beams, and drawing wire. The names of many extensive iron and steel works, in some of which large plants have been in use for years, will be given on application.

WEIGHT AND VOLUME OF AIR.

A cubic foot of air at 60° and under average atmospheric pressure, at sea level, weighs 536 grains, and 13.06 cubic feet weigh one pound. Air expands or contracts an equal amount with each degree of variation in temperature. Its weight and volume at any temperature under 30 inches of barometer may be found within less than one-half of one per cent. by the following formula, in which W = weight in pounds of one cubic foot, V = volume in cubic feet, per pound, and τ = absolute temperature, or 460° added to that by the thermometer, $= t + 460$.

$$W = \frac{40}{\tau} \qquad V = \frac{\tau}{40}$$

For any condition of pressure and temperature the following formulas are very nearly exact:—

$$W = 2.71\frac{p}{\tau} \quad . \; . \quad V = \frac{\tau}{2.71p} \quad . \; . \quad t = 2.71\,Vp - 460$$

in which p is pressure above absolute vacuum. The same formulas answer for any other gas by changing the co-efficient.

American Surety Building. 480 H.P. Babcock & Wilcox Boilers.

CHIMNEYS

Chimneys are required for two purposes — 1st, to carry off obnoxious gases; 2d, to produce a draft, and so facilitate combustion. The first requires size, the second height.

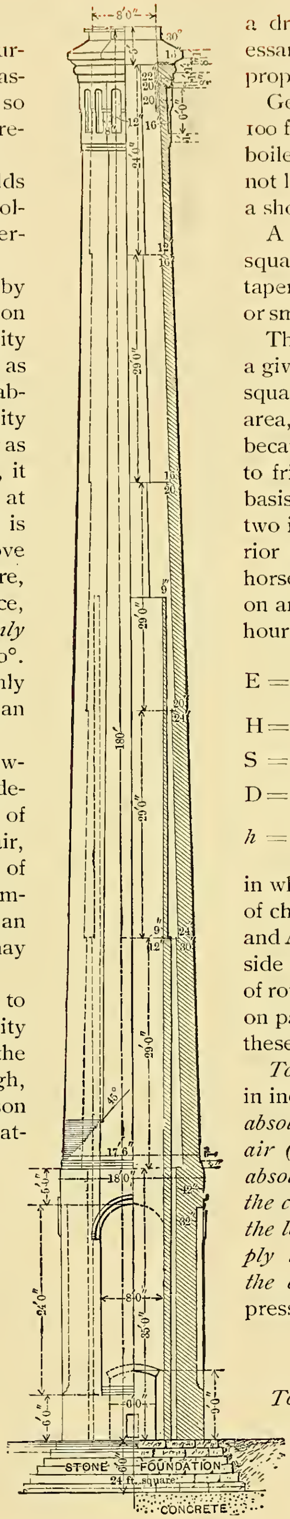
Each pound of coal burned yields from 13 to 30 pounds of gas, the volume of which varies with the temperature.

The weight of gas to be carried off by a chimney in a given time depends upon three things — size of chimney, velocity of flow, and density of gas. But as the density decreases directly as the absolute temperature, while the velocity increases, with a given height, nearly as the square root of the temperature, it follows that there is a temperature at which the weight of gas delivered is a maximum. This is about 550° above the surrounding air. Temperature, however, makes so little difference, that at 550° above, the quantity is *only four per cent.* greater than at 300°. Therefore, height and area are the only elements necessary to consider in an ordinary chimney.

The intensity of draft is, however, independent of the size, and depends upon the difference in weight of the outside and inside columns of air, which varies nearly as the product of the height into the difference of temperature. This is usually stated in an equivalent column of water, and may vary from 0 to possibly 2 inches.

After a height has been reached to produce draft of sufficient intensity to burn fine, hard coal, provided the area of the chimney is large enough, there seems no good mechanical reason for adding further to the height, whatever the size of the chimney required. Where cost is no consideration there is no objection to building as high as one pleases; but for the purely utilitarian purpose of steam making equally good results might be attained with a shorter chimney at much less cost.

The intensity of draft required varies with the kind and condition of the fuel, and the thickness of the fires. Wood requires the least, and fine coal or slack the most. To burn anthracite slack to advantage,



a draft of 1¼ inch of water is necessary, which can be attained by a well-proportioned chimney 175 feet high.

Generally a much less height than 100 feet cannot be recommended for a boiler, as the lower grades of fuel cannot be burned as they should be with a shorter chimney.

A round chimney is better than square, and a straight flue better than a tapering, though it may be either larger or smaller at the top without detriment.

The effective area of a chimney for a given power varies inversely as the square root of the height. The actual area, in practice, should be greater, because of retardation of velocity due to friction against the walls. On the basis that this is equal to a layer of air two inches thick over the whole interior surface, and that a commercial horse-power requires the consumption on an average of 5 pounds of coal per hour, we have the following formulas:—

$$E = \frac{0.3\ H}{\sqrt{h}} = A - 0.6\sqrt{A} \quad . \quad . \quad . \quad 1$$

$$H = 3.33\ E\sqrt{h} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 2$$

$$S = 12\sqrt{E} + 4 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 3$$

$$D = 13.54\sqrt{E} + 4 \quad . \quad . \quad . \quad . \quad . \quad . \quad 4$$

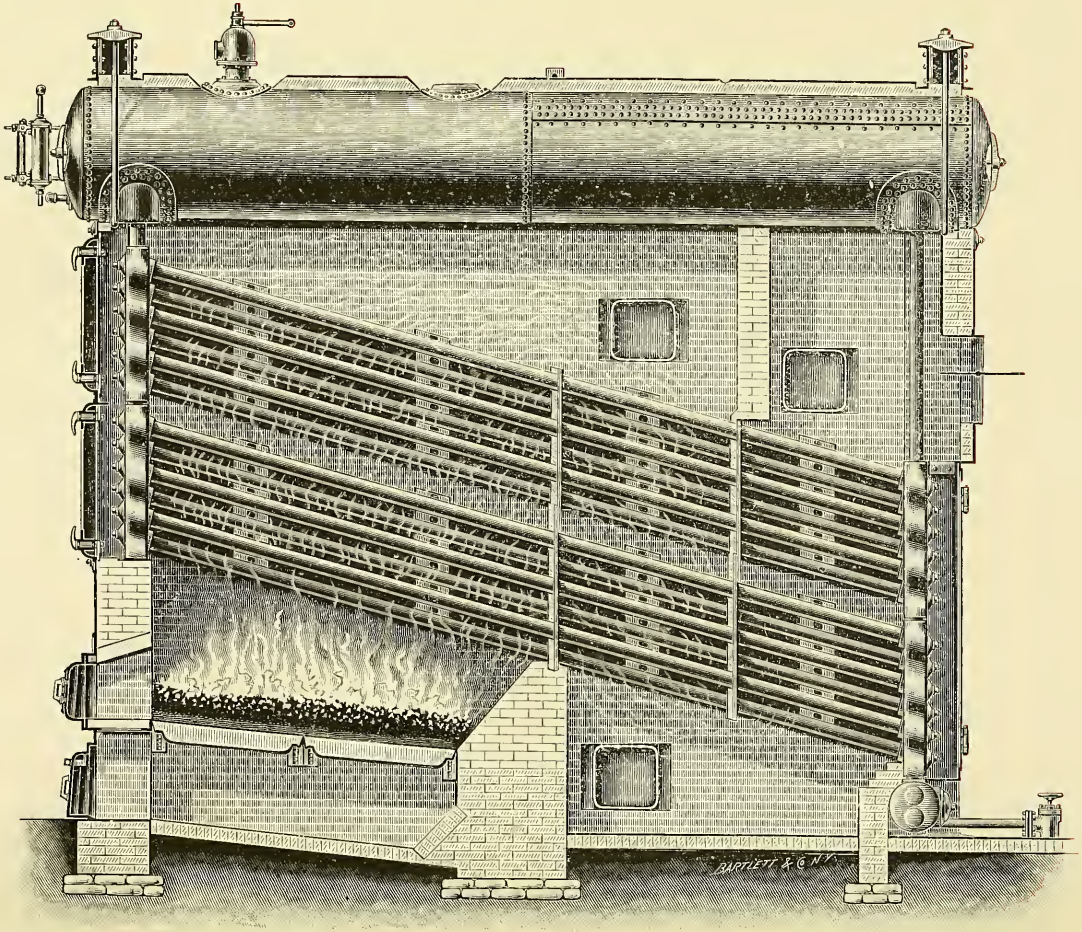
$$h = \left(\frac{0.3\ H}{E}\right)^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 5$$

in which H = horse-power; h = height of chimney in feet; E = effective area, and A = actual area in square feet; S = side of square chimney, and D = dia. of round chimney in inches. The table on page 71 is calculated by means of these formulas.

To find the draft of a given chimney in inches of water: *Divide 7.6 by the absolute temperature of the external air ($\tau_a = t + 460$); divide 7.9 by the absolute temperature of the gases in the chimney ($\tau_c = t' + 460$); subtract the latter from the former, and multiply the remainder by the height of the chimney in feet.* This rule, expressed in a formula, would be:—

$$d = h\left(\frac{7.6}{\tau_a} - \frac{7.9}{\tau_c}\right).$$

To find the height of a chimney, to give a specific draft power, expressed in inches of water: *Proceed as above, through the first two steps, then divide the given draft power*

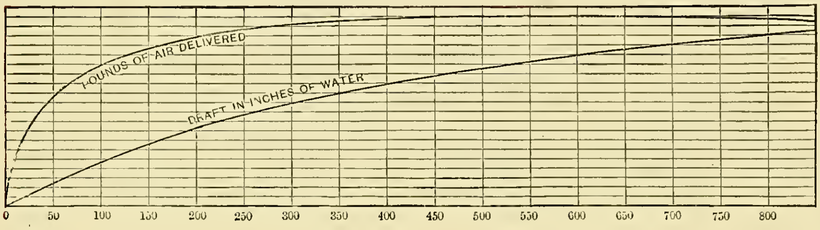


Side View of Vertical Header Double Deck Boiler.

by the remainder, the result is the height in feet. Or, by formula :—

$$h = \frac{d}{\left(\frac{7.6}{T_a} - \frac{7.9}{T_c}\right)}$$

To find the maximum efficient draft for any given chimney, the heated column being 600 F., and the external air 62° : *Multiply the height above grate in feet by .007, and the product is the draft power in inches of water.*



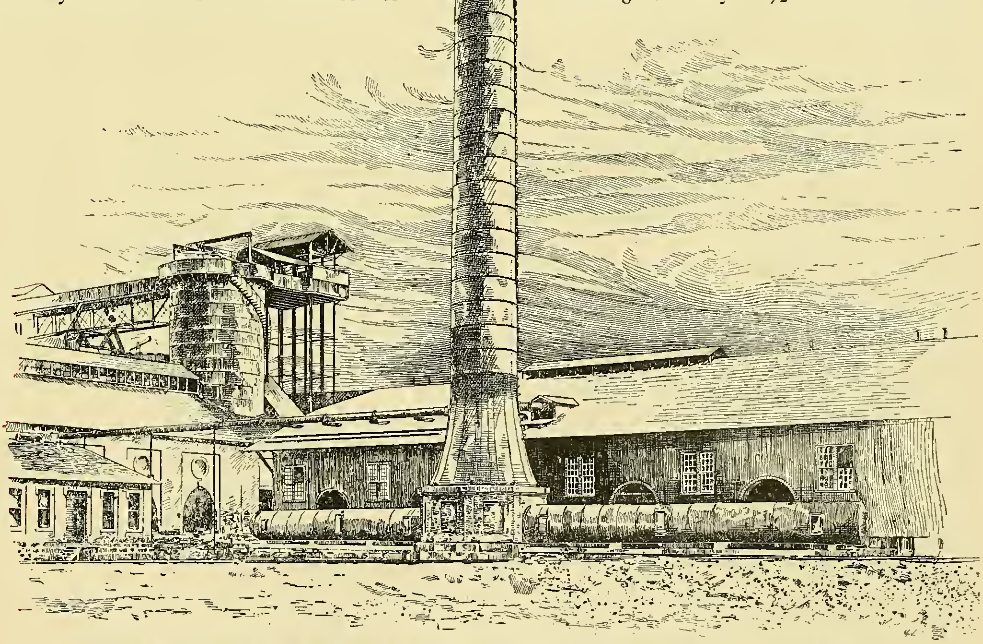
The above diagram shows the draft, in inches, of water for a chimney 100 feet high, under different temperatures, from 50° to 800° above external atmosphere, which is assumed at 60°. The vertical scale is full size, and each division is $\frac{1}{20}$ of an inch. It also shows the relative quantity, in pounds of air, which would be delivered, in the same time, by a chimney under the same differences of temperature. It will be seen that practically nothing can be gained by carrying the temperature of the chimney more than 350° above the external air at 60°.

To determine the quantity of air, in pounds, a given chimney will deliver per hour, multiply the distance in inches, at given temperature, on the diagram, by 1000 times the effective area in square feet, and by the square root of the height in feet. This gives a maximum. Friction in flues and furnace may reduce it greatly.

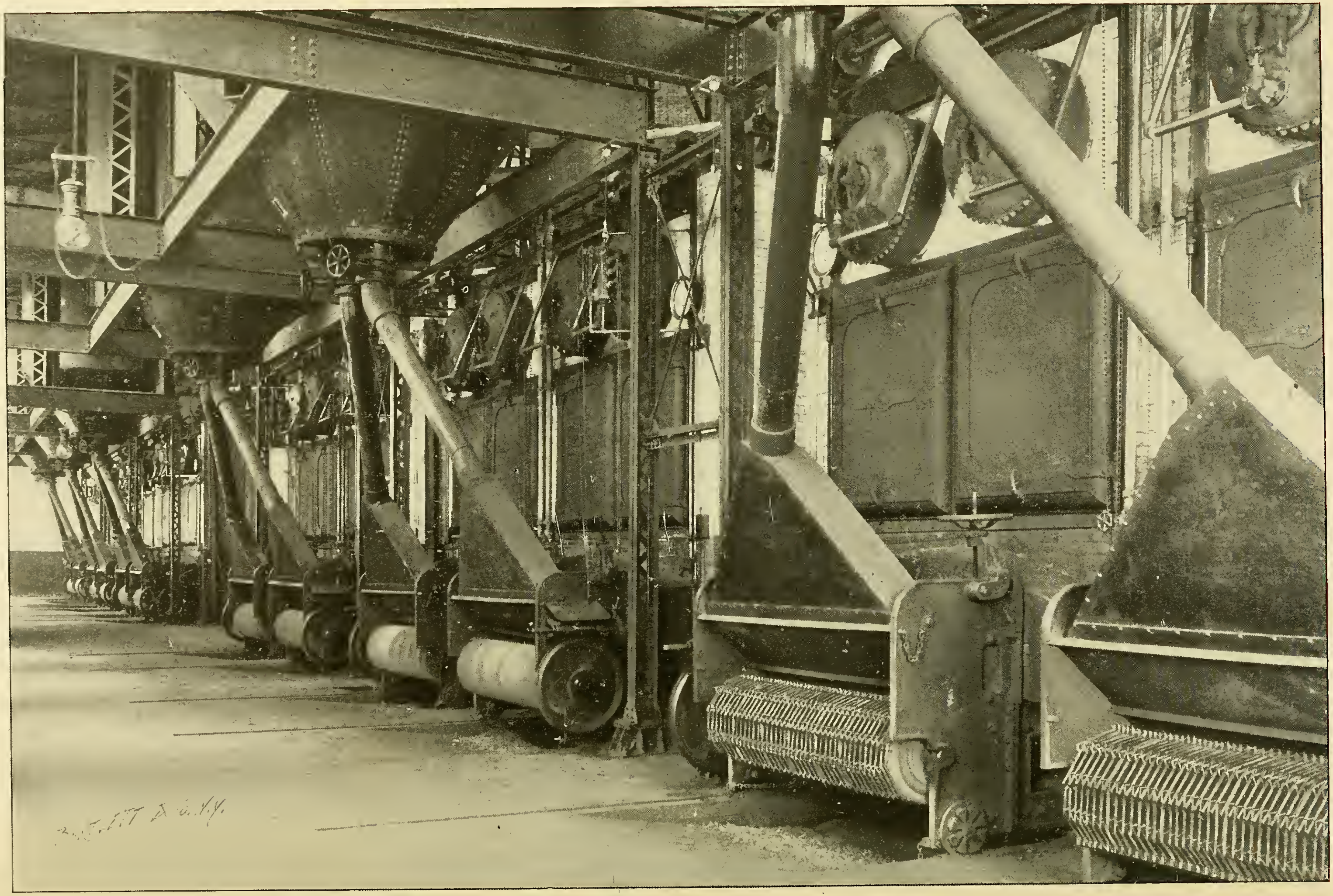
The external diameter of a brick chimney at the base should be one-tenth the height, unless it be supported by some other structure. The "batter" or taper of a chimney should be from $\frac{1}{16}$ to ¼ inch to the foot on each side.

Thickness of brick work : one brick (8 or 9 inches) for 25 ft. from the top, increasing ½ brick (4 or 4½ inches) for each 25 ft. from the top downwards.

If the inside diameter exceed 5 ft. the top length should be 1½ bricks, and if under 3 ft. it may be ½ brick for ten feet.



Chimney for 1260 H.P. of Babcock & Wilcox Boiler, at Bird Coleman Furnace, Cornwall, Pa.



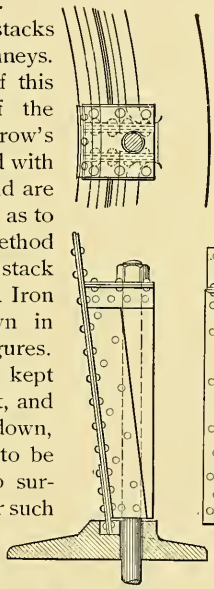
Atlas Cement Co., Northampton, Pa. Babcock & Wilcox Boilers with Chain Grate Stokers. 9000 H. P. in use.

SIZES OF CHIMNEYS WITH APPROPRIATE HORSE-POWER OF BOILERS.

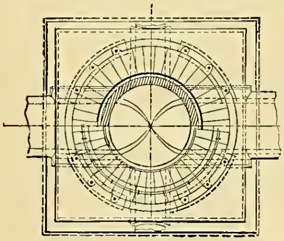
Diameter in Inches.	Height of Chimneys and Commercial Horse-Power.											Side of Square. Inches.	Effective Area. Square Feet.	Actual Area. Square Feet.
	50 ft.	60 ft.	70 ft.	80 ft.	90 ft.	100 ft.	110 ft.	125 ft.	150 ft.	175 ft.	200 ft.			
18	23	25	27	...	...	....	....	....	....	....	....	16	0.97	1.77
21	35	38	41	...	...	....	....	....	....	....	....	19	1.47	2.41
24	49	54	58	62	...	....	....	....	....	....	....	22	2.08	3.14
27	65	72	78	83	...	....	....	....	....	....	....	24	2.78	3.98
30	84	92	100	107	113	....	....	....	....	....	....	27	3.58	4.91
33	..	115	125	133	141	....	....	....	....	....	....	30	4.48	5.94
36	..	141	152	163	173	182	....	....	....	....	....	32	5.47	7.07
39	..	...	183	196	208	219	....	....	....	....	....	35	6.57	8.30
42	..	...	216	231	245	258	271	....	....	....	....	38	7.76	9.62
48	..	...	...	311	330	348	365	389	....	....	....	43	10.44	12.57
54	..	...	...	363	427	449	472	503	551	....	....	48	13.51	15.90
60	..	...	...	505	536	565	593	632	692	748	....	54	16.98	19.64
66	..	...	...	...	658	694	728	776	849	918	981	59	20.83	23.76
72	..	...	...	...	792	835	876	934	1023	1105	1181	64	25.08	28.27
78	..	...	...	...	...	995	1038	1107	1212	1310	1400	70	29.73	33.18
84	..	...	...	...	...	1163	1214	1294	1418	1531	1637	75	34.76	38.48
90	..	...	...	...	...	1344	1415	1496	1639	1770	1893	80	40.19	44.18
96	..	...	...	...	...	1537	1616	1720	1876	2027	2167	86	46.01	50.27
102	..	...	...	...	...	....	....	1946	2133	2303	2462	90	52.23	56.75
108	..	...	...	...	...	....	....	2192	2402	2594	2773	96	58.83	63.62
114	..	...	...	...	...	....	....	2459	2687	2903	3003	101	65.83	70.88
120	..	...	...	...	...	....	....	....	2990	3230	3452	106	73.22	78.54
126	..	...	...	...	...	....	....	....	3308	3573	3820	112	81.00	86.59
132	..	...	...	...	...	....	....	....	3642	3935	4205	117	89.19	95.03
138	..	...	...	...	...	....	....	....	3991	4311	4608	122	97.75	103.86
144	..	...	...	...	...	....	....	....	4357	4707	5031	127	106.72	113.10

IRON CHIMNEY STACKS.

In many places iron stacks are preferred to brick chimneys. The cuts on the margin of this page show the stacks of the Maryland Steel Co., at Sparrow's Point, Md. These are lined with brick their whole height and are bolted down to the base so as to require no stays. A good method of securing such bolts to the stack is practiced by the Pencoyd Iron Works, Pa., and is shown in detail in the annexed figures. Iron stacks require to be kept well painted to prevent rust, and generally, where not bolted down, as here shown, they need to be braced by rods or wires to surrounding objects. With four such braces attached to an angle iron ring at ⅔ the height of stack, and spreading laterally at least an equal distance, each brace should have an area in square inches equal to 1-1000 the exposed area of stack (dia. × height) in feet.



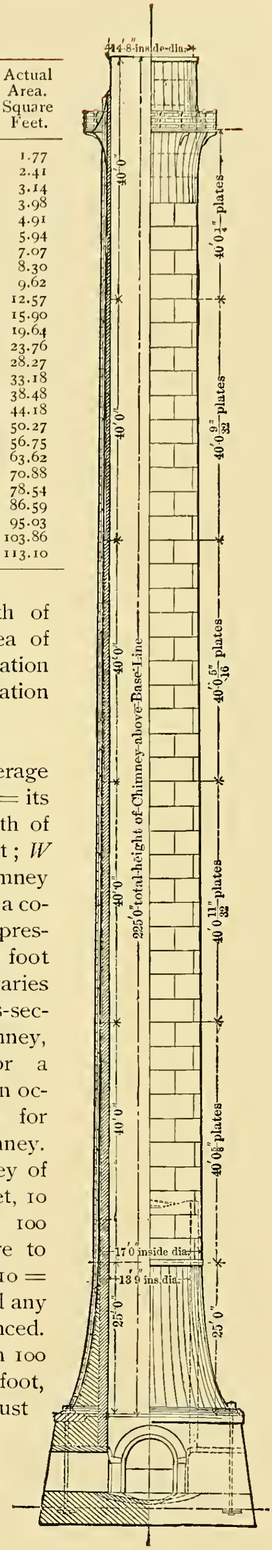
Holding Down Bolts and Lugs, Pencoyd Iron Works.



STABILITY, or power to withstand the overturning force of the highest winds, requires a proportionate relation between the weight, height, breadth of base, and exposed area of the chimney. This relation is expressed in the equation

$$C \frac{d h^2}{b} = W,$$

in which d = the average breadth of the shaft; h = its height; b = the breadth of base,—all in feet; W = weight of chimney in lbs., and C = a coefficient of wind pressure per square foot of area. This varies with the cross-section of the chimney, and = 56 for a square, 35 for an octagon, and 28 for a round chimney. Thus a square chimney of average breadth of 8 feet, 10 feet wide at base and 100 feet high, would require to weigh 56 × 8 × 100 × 10 = 448,000 lbs. to withstand any gale likely to be experienced. Brickwork weighs from 100 to 130 lbs. per cubic foot, hence such a chimney must average 13 inches thick to be safe. A round stack could weigh half as much, or have less base.



Land Title & Trust Co. Building, Philadelphia, Pa. 350 H.P. Babcock & Wilcox Boilers

PROPERTIES OF SATURATED STEAM.

Ice is liquified and becomes water at 32° F. Above this point water increases in temperature up to the steaming point, nearly at the rate of 1° for each unit of heat added per pound of water. The steaming point (212° at atmospheric pressure) rises as the superimposed pressure increases, but at a decreasing ratio; as, for example, at atmospheric pressure it takes 3½° to add a pound, while at 150 pounds ½° gives the same increase of pressure.

For each unit of heat added above the steaming point, a portion of the water is converted into steam, having the same temperature and the same pressure as that at which it is evaporated. The heat so absorbed is called "Latent Heat." The amount of heat rendered latent by each pound of water in becoming steam varies at different pressures, decreasing as the pressure increases. This latent heat added to the sensible heat (or the thermometric temperature) constitutes the "Total Heat." The "total heat" being greater as the pressure increases, it will take more heat, and consequently more fuel, to make a pound of steam the higher the pressure.

Saturated steam cannot be cooled except by lowering its pressure, the abstraction of heat being compensated by the latent heat of a portion which is condensed. Neither can steam, in contact with water, be heated above the temperature normal to its pressure.

The density of saturated steam varies from ⅝ that of air of the same temperature and pressure, below that of the atmosphere, to ⅔ at 100 pounds. Its weight per cubic foot varies as the 17th root of the 16th power, and may be found by the formula: $D = .003027 p^{.941}$, which is correct to within $\frac{1}{7}$ per cent. up to 250 pounds pressure.

The following table gives the properties of steam at different pressures — from 1 lb. to 500.

TABLE OF PROPERTIES OF SATURATED STEAM, Partly from C. H. Peabody's Tables.

Pressure in pounds per square inch above vacuum.	Temperature in degrees, Fahrenheit.	Total heat in heat units from water at 32°.	Heat in liquid from 32° in units.	Heat of vaporization, or latent heat in heat units.	Density or weight of cubic foot in pounds.	Volume of one pound in cubic feet.	Factor of equivalent evaporation at 212°.	Total pressure above vacuum.
1	101.99	1113.1	70.0	1043.0	0.00299	334.5	.9661	1
2	126.27	1120.5	94.4	1026.1	0.00576	173.6	.9738	2
3	141.62	1125.1	109.8	1015.3	0.00844	118.5	.9786	3
4	153.09	1128.6	121.4	1007.2	0.01107	90.33	.9822	4
5	162.34	1131.5	130.7	1000.8	0.01366	73.21	.9852	5
6	170.14	1133.8	138.6	995.2	0.01622	61.65	.9876	6
7	176.90	1135.9	145.4	990.5	0.01874	53.39	.9897	7
8	182.92	1137.7	151.5	986.2	0.02125	47.06	.9916	8
9	188.33	1139.4	156.9	982.5	0.02374	42.12	.9934	9
10	193.25	1140.9	161.9	979.0	0.02621	38.15	.9949	10
15	213.03	1146.9	181.8	965.1	0.03826	26.14	1.0003	15
20	227.95	1151.5	196.9	954.6	0.05023	19.91	1.0051	20
25	240.04	1155.1	209.1	946.0	0.06199	16.13	1.0099	25
30	250.27	1158.3	219.4	938.9	0.07360	13.59	1.0129	30
35	259.19	1161.0	228.4	932.6	0.08508	11.75	1.0157	35
40	267.13	1163.4	236.4	927.0	0.09644	10.37	1.0182	40
45	274.29	1165.6	243.6	922.0	0.1077	9.285	1.0205	45
50	280.85	1167.6	250.2	917.4	0.1188	8.418	1.0225	50
55	286.89	1169.4	256.3	913.1	0.1299	7.698	1.0245	55
60	292.51	1171.2	261.9	909.3	0.1409	7.097	1.0263	60
65	297.77	1172.7	267.2	905.5	0.1519	6.583	1.0280	65
70	302.71	1174.3	272.2	902.1	0.1628	6.143	1.0295	70
75	307.38	1175.7	276.9	898.8	0.1736	5.760	1.0309	75
80	311.80	1177.0	281.4	895.6	0.1843	5.426	1.0323	80
85	316.02	1178.3	285.8	892.5	0.1951	5.126	1.0337	85
90	320.04	1179.6	290.0	889.6	0.2058	4.859	1.0350	90
95	323.89	1180.7	294.0	886.7	0.2165	4.619	1.0362	95
100	327.58	1181.9	297.9	884.0	0.2271	4.403	1.0374	100
105	331.13	1182.9	301.6	881.3	0.2378	4.205	1.0385	105
110	334.56	1184.0	305.2	878.8	0.2484	4.026	1.0396	110
115	337.86	1185.0	308.7	876.3	0.2589	3.862	1.0406	115
120	341.05	1186.0	312.0	874.0	0.2695	3.711	1.0416	120
125	344.13	1186.9	315.2	871.7	0.2800	3.571	1.0426	125
130	347.12	1187.8	318.4	869.4	0.2904	3.444	1.0435	130
140	352.85	1189.5	324.4	865.1	0.3113	3.212	1.0453	140
150	358.26	1191.2	330.0	861.2	0.3321	3.011	1.0470	150
160	363.40	1192.8	335.4	857.4	0.3530	2.833	1.0486	160
170	368.29	1194.3	340.5	853.8	0.3737	2.676	1.0502	170
180	372.97	1195.7	345.4	850.3	0.3945	2.535	1.0517	180
190	377.44	1197.1	350.1	847.0	0.4153	2.408	1.0531	190
200	381.73	1198.4	354.6	843.8	0.4359	2.294	1.0545	200
225	391.79	1201.4	365.1	836.3	0.4876	2.051	1.0576	225
250	400.99	1204.2	374.7	829.5	0.5393	1.854	1.0605	250
275	409.50	1206.8	383.6	823.2	0.5913	1.691	1.0632	275
300	417.42	1209.3	391.9	817.4	0.644	1.553	1.0657	300
325	424.82	1211.5	399.6	811.9	0.696	1.437	1.0680	325
350	431.90	1213.7	406.9	806.8	0.748	1.337	1.0703	350
375	438.40	1215.7	414.2	801.5	0.800	1.250	1.0724	375
400	445.15	1217.7	421.4	796.3	0.853	1.172	1.0745	400
500	466.57	1224.2	444.3	779.9	1.065	.939	1.0812	500

Empire Building, New York. 911 H.P. Babcock & Wilcox Boilers.

The gauge pressure is about 15 pounds (14.7) less than the total pressure, so that in using this table, 15 must be added to the pressure as given by the steam gauge. The column of Temperatures gives the thermometric temperature of steam and the boiling point at each pressure. The "factor of equivalent evaporation" shows the proportionate cost in heat or fuel of producing steam at the given pressure as compared with atmospheric pressure.

To ascertain the equivalent evaporation at any pressure, multiply the given evaporation by the factor of its pressure, and divide the product by the factor of the desired pressure.

Each degree of difference in temperature of feed-water makes a difference of .00104 in the amount of evaporation. Hence, to ascertain the equivalent evaporation from any other temperature of feed than 212°, add to the factor given as many times .00104 as the temperature of feed-water is degrees below 212°. For other pressures than those given in the table, it will be practically correct to take the proportion of the difference between the nearest pressures given in the table.

FACTORS OF EVAPORATION.

From the Tables computed by Mr. Geo. A. Rowell.

Temp're of Feed Water. Deg. Fahr.	Steam Pressure by Gauge.																									
	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300
32	1.214	1.216	1.220	1.222	1.225	1.227	1.229	1.231	1.232	1.234	1.236	1.237	1.239	1.240	1.241	1.243	1.244	1.245	1.246	1.247	1.248	1.250	1.251	1.252	1.253	1.254
40	1.206	1.209	1.212	1.214	1.216	1.219	1.220	1.222	1.224	1.226	1.227	1.229	1.230	1.232	1.233	1.234	1.236	1.237	1.238	1.239	1.240	1.241	1.242	1.243	1.244	1.245
50	1.195	1.197	1.201	1.204	1.206	1.208	1.210	1.212	1.214	1.215	1.217	1.218	1.220	1.221	1.223	1.224	1.225	1.226	1.228	1.229	1.230	1.231	1.232	1.233	1.234	1.235
60	1.185	1.188	1.191	1.193	1.196	1.198	1.200	1.202	1.203	1.205	1.207	1.208	1.210	1.211	1.212	1.214	1.215	1.216	1.217	1.218	1.219	1.220	1.221	1.222	1.223	1.224
70	1.175	1.178	1.180	1.183	1.185	1.187	1.189	1.191	1.193	1.194	1.196	1.197	1.199	1.200	1.202	1.203	1.205	1.206	1.207	1.208	1.209	1.210	1.211	1.212	1.213	1.214
80	1.164	1.167	1.170	1.173	1.175	1.177	1.179	1.181	1.183	1.184	1.186	1.187	1.189	1.190	1.192	1.193	1.194	1.195	1.196	1.198	1.199	1.200	1.201	1.202	1.203	1.204
90	1.154	1.157	1.160	1.162	1.165	1.167	1.169	1.170	1.172	1.174	1.176	1.177	1.179	1.180	1.181	1.183	1.184	1.185	1.186	1.187	1.188	1.189	1.190	1.191	1.192	1.193
100	1.144	1.147	1.150	1.152	1.154	1.156	1.158	1.160	1.162	1.164	1.165	1.167	1.168	1.170	1.171	1.172	1.174	1.175	1.176	1.177	1.178	1.179	1.180	1.181	1.182	1.183
110	1.133	1.136	1.139	1.142	1.144	1.146	1.148	1.150	1.152	1.153	1.155	1.156	1.158	1.159	1.160	1.162	1.163	1.164	1.166	1.167	1.168	1.169	1.170	1.171	1.172	1.173
120	1.123	1.126	1.129	1.131	1.133	1.136	1.138	1.140	1.141	1.143	1.145	1.146	1.147	1.149	1.150	1.151	1.153	1.154	1.155	1.156	1.157	1.158	1.159	1.160	1.161	1.162
130	1.113	1.116	1.118	1.121	1.123	1.125	1.127	1.129	1.130	1.132	1.134	1.136	1.137	1.138	1.140	1.141	1.142	1.144	1.145	1.146	1.147	1.148	1.149	1.150	1.151	1.152
140	1.102	1.105	1.108	1.110	1.113	1.115	1.117	1.119	1.120	1.122	1.124	1.125	1.127	1.128	1.129	1.131	1.132	1.133	1.134	1.135	1.136	1.137	1.138	1.139	1.140	1.141
150	1.091	1.095	1.098	1.100	1.102	1.104	1.106	1.108	1.110	1.111	1.113	1.115	1.116	1.118	1.119	1.120	1.121	1.123	1.124	1.125	1.126	1.127	1.128	1.129	1.130	1.131
160	1.081	1.084	1.087	1.090	1.092	1.094	1.096	1.098	1.100	1.101	1.103	1.104	1.106	1.107	1.108	1.110	1.111	1.112	1.113	1.115	1.116	1.117	1.118	1.119	1.120	1.121
170	1.070	1.074	1.077	1.079	1.081	1.083	1.085	1.087	1.089	1.091	1.092	1.094	1.095	1.097	1.098	1.099	1.101	1.102	1.103	1.104	1.105	1.106	1.107	1.108	1.109	1.110
180	1.060	1.063	1.066	1.069	1.071	1.073	1.075	1.077	1.079	1.080	1.082	1.083	1.085	1.086	1.088	1.089	1.090	1.091	1.093	1.094	1.095	1.096	1.097	1.098	1.099	1.100
190	1.050	1.053	1.056	1.058	1.060	1.063	1.065	1.066	1.068	1.070	1.071	1.073	1.074	1.076	1.077	1.078	1.080	1.081	1.082	1 083	1.084	1.085	1.086	1.087	1.088	1.089
200	1.039	1.043	1.045	1.048	1.050	1.052	1.054	1.056	1.058	1.059	1.061	1.063	1.064	1.065	1.067	1.068	1.069	1.071	1.072	1.073	1.074	1.075	1.076	1.077	1.078	1.079
210	1.029	1.032	1.035	1.037	1.040	1.042	1.044	1.046	1.047	1.049	1.051	1.052	1.053	1.055	1.056	1.057	1.059	1.060	1.061	1.062	1.063	1.064	1.065	1.066	1.067	1.068

WATER AT DIFFERENT TEMPERATURES.

There are four notable temperatures for pure water, viz.: —

1. Freezing point at sea level, ... 32° F.
2. Point of maximum density, ... 39.1° F.
3. British standard for specific gravity, . 62° F.
4. Boiling point at sea level, ... 212° F.

32° F. Weight per cub. ft., 62.418 lb.; per cub. in., .03612 lb.
39.1° F. Weight per cub. ft., 62.425 lb.; per cub. in., .036125lb.
62° F. Weight per cub. ft., 62.355 lb.; per cub. in., .03608 lb.
212° F. Weight per cub. ft., 59.760 lb.; per cub. in., .03458 lb.

A United States Standard gallon holds 231 cubic inches and 8⅓ lbs. of water at 62° F.

A British Imperial gallon holds 277.274 cubic inches and 10 lbs. of water at 62° F.

Sea water (average) has a specific gravity of 1.028, boils at 213.2° F., and weighs 64 lbs. per cubic foot at 62° F.

A pressure of 1 lb. per sq. in. is exerted by a column of water 2.3093 ft., or 27.71 in. high, at 62° F.

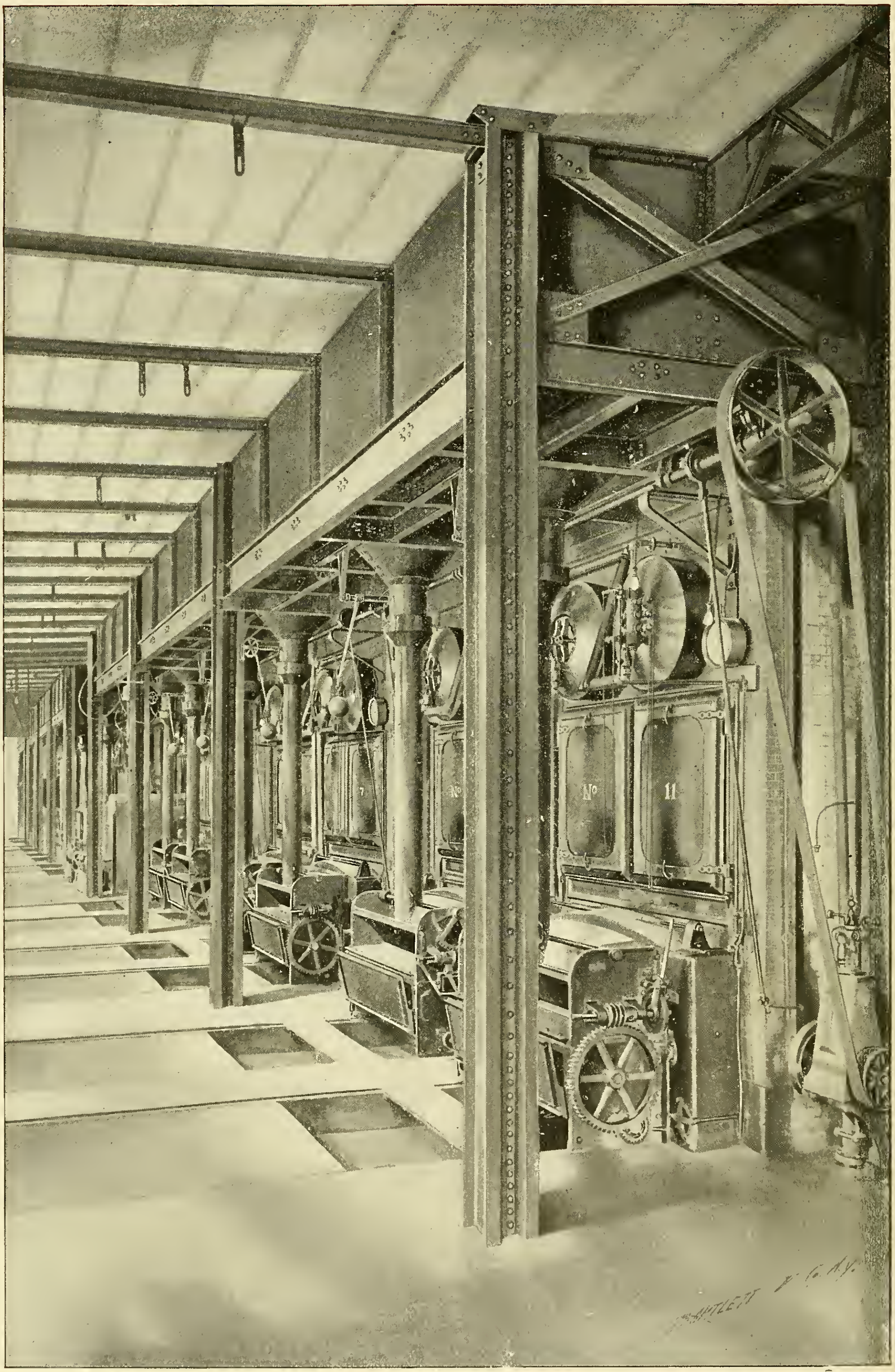
In solvent power water has a greater range than any other liquid. For common salt this is nearly constant at all temperatures, while it increases with increase of temperature for others, magnesium and sodium sulphates, for instance. Where water contains carbonic acid it dissolves some minerals quite readily, but a boiling temperature causes the disengagement of the carbonic acid in gaseous form and the deposition of a large part of the minerals thus held in solution.

Lime salts are more soluble in cold than in hot water, and most of them are deposited at 320°, or less. When frozen into ice, or evaporated into steam, water parts with nearly all substances held in solution.

TABLE OF SOLUBILITIES OF SCALE-MAKING MINERALS.

Substance.	Soluble in parts of pure water at 32° F.	Soluble in parts carbonic acid water, cold.	Soluble in parts of pure water at 212°.	Insoluble in water at
Carbonate of Lime, . .	62,500	150	62,500	302° F.
Sulphate of Lime, . . .	500	....	460	302° F.
Carbonate of Magnesia, .	5,500	150	9,600	....
Phosphate of Lime, . .	....	1,333	....	212° F.
Oxide of Iron, ...	....	....	....	212° F.
Silica, ...	....	Und't'd	....	212° F.

Water has a greater specific heat, or heat-absorbing capacity, than any other known sub-



Metropolitan West Side Elevated Railroad, Chicago. 7700 H.P. Babcock & Wilcox Boilers and Chain Grate Stokers.

stance (bromine and hydrogen excepted), and is the unit of comparison employed for all measurements of the capacities for heat of all substances whatever. The specific heat of water is not constant, but rises in an increasing ratio with the temperature, so that it requires slightly more heat, the higher the temperature, to raise a given quantity of water from one temperature to another. The specific heat of ice and steam are, respectively, .504 and .475, or practically about half that of water.

A British Thermal Unit (or heat unit) is that quantity of heat which will raise one pound of water at or about freezing point, 1° F. A French "Calorie" is the heat required to raise one kilogramme of water 1° C., and is equal to 3.96832 British thermal units.

The following table gives the number of British thermal units in a pound of water at different temperatures. They are reckoned above 32° F., for, strictly speaking, *water* does not exist below 32°, and ice follows another law.

WATER BETWEEN 32° AND 212° F.

Temperature Fahr.	Heat Units per lb.	Weight, lbs. per cubic foot.	Temperature Fahr.	Heat Units per lb.	Weight, lbs. per cubic foot.	Temperature Fahr.	Heat Units per lb.	Weight, lbs. per cubic foot.	Temperature Fahr.	Heat Units per lb.	Weight, lbs. per cubic foot.
32°	0.00	62.42	110°	78.00	61.89	145°	113.26	61.28	179°	147.54	60.57
35	3.02	62.42	112	80.00	61.86	146	114.27	61.26	180	148.54	60.55
40	8.06	62.42	113	81.01	61.84	147	115.28	61.24	181	149.55	60.53
45	13.08	62.42	114	82.02	61.83	148	116.29	61.22	182	150.56	60.50
50	18.10	62.41	115	83.02	61.82	149	117.30	61.20	183	151.57	60.48
52	20.11	62.40	116	84.03	61.80	150	118.30	61.18	184	152.58	60.46
54	22.11	62.40	117	85.04	61.78	151	119.31	61.16	185	153.58	60.44
56	24.11	62.39	118	86.05	61.77	152	120.32	61.14	186	154.59	60.41
58	26.12	62.38	119	87.06	61.75	153	121.33	61.12	187	155.60	60.39
60	28.12	62.37	120	88.06	61.74	154	122.34	61.10	188	156.61	60.37
62	30.12	62.36	121	89.07	61.72	155	123.34	61.08	189	157.62	60.34
64	32.12	62.35	122	90.08	61.70	156	124.35	61.06	190	158.62	60.32
66	34.12	62.34	123	91.09	61.68	157	125.36	61.04	191	159.63	60.29
68	36.12	62.33	124	92.10	61.67	158	126.37	61.02	192	160.63	60.27
70	38.11	62.31	125	93.10	61.65	159	127.38	61.00	193	161.64	60.25
72	40.11	62.30	126	94.11	61.63	160	128.38	60.98	194	162.65	60.22
74	42.11	62.28	127	95.12	61.61	161	129.39	60.96	195	163.66	60.20
76	44.11	62.27	128	96.13	61.60	162	130.40	60.94	196	164.66	60.17
78	46.10	62.25	129	97.14	61.58	163	131.41	60.92	197	165.07	60.15
80	48.09	62.23	130	98.14	61.56	164	132.42	60.90	198	166.68	60.12
82	50.08	62.21	131	99.15	61.54	165	133.42	60.87	199	167.69	60.10
84	52.07	62.19	132	100.16	61.52	166	134.43	60.85	200	168.70	60.07
86	54.06	62.17	133	101.17	61.51	167	135.44	60.83	201	169.70	60.05
88	56.05	62.15	134	102.18	61.49	168	136.45	60.81	202	170.71	60.02
90	58.04	62.13	135	103.18	61.47	169	137.46	60.79	203	171.72	60.00
92	60.03	62.11	136	104.19	61.45	170	138.46	60.77	204	172.73	59.97
94	62.02	62.09	137	105.20	61.43	171	139.47	60.75	205	173.74	59.95
96	64.01	62.07	138	106.21	61.41	172	140.48	60.73	206	174.74	59.92
98	66.01	62.05	139	107.22	61.39	173	141.49	60.70	207	175.75	59.89
100	68.01	62.02	140	108.22	61.37	174	142.50	60.68	208	176.76	59.87
102	70.00	62.00	141	109.23	61.36	175	143.50	60.66	209	177.77	59.84
104	72.00	61.97	142	110.24	61.34	176	144.51	60.64	210	178.78	59.82
106	74.00	61.95	143	111.25	61.32	177	145.52	60.62	211	179.78	59.79
108	76.00	61.92	144	112.26	61.30	178	146.53	60.59	212	180.79	59.76

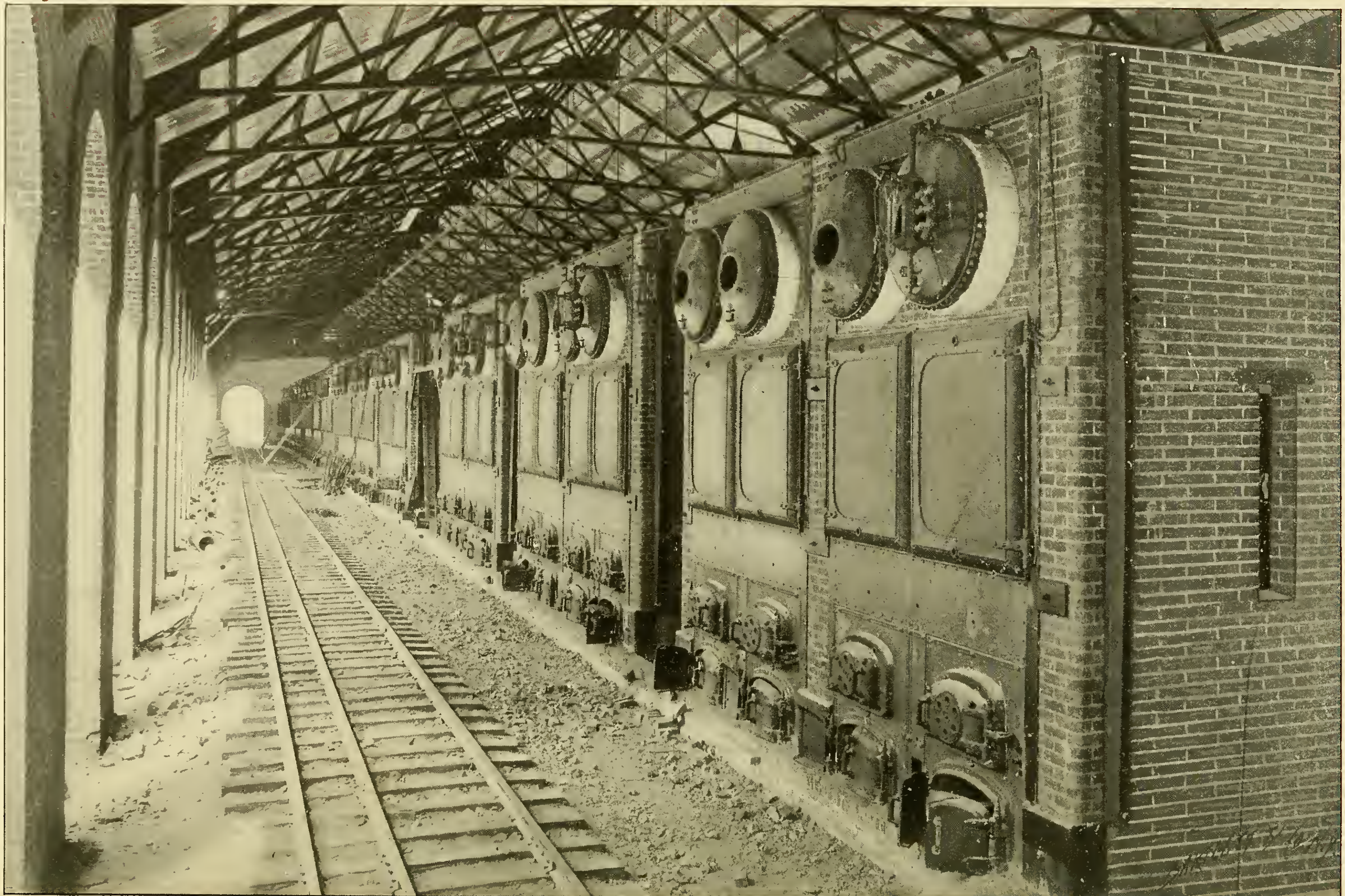
PRIMING OR WET STEAM.

A fault, frequently met with in steam boilers, is the carrying over of water mechanically mixed with the steam, which water not only carries away heat without any useful effect, but, when present in any marked quantity, itself becomes a source of danger and of serious loss in the engine. This is a point frequently forgotten in designing boilers, particularly sectional boilers. If steam rises from a surface of water faster than about 2 ft. 6 in. to 3 ft. per second, it carries water with it in the form of spray, and when a fine spray is once formed in steam it does not readily settle against a rising current of very low velocity, as a current of 1 ft. per second will carry with it a globule of water $\frac{1}{1000}$ of an inch in diameter.

Many boilers show a high apparent evaporation in consequence of furnishing "wet steam," while practically they are anything but economical. Parties have been known to claim an evaporation of 19 or 20 pounds per pound of coal, where the highest practically possible is not over 13. Such boilers are dear at any price.

The cause of priming may be either impure water, too much water, or improper proportions in the boiler. When a boiler is found to form wet steam with good water, carried at a proper height, it is a proof of wrong design.

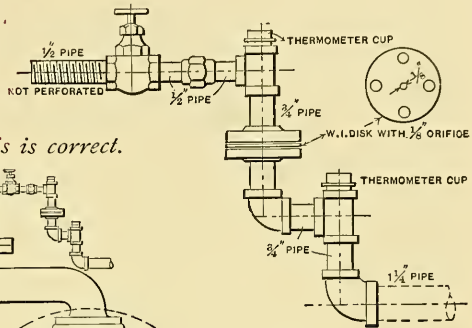
The amount of priming in different boilers varies greatly, and as yet there is not sufficient data to establish any definite ratio for boilers in ordinary use. The experiments of M. Hirn, at



6000 H. P. Babcock & Wilcox Boilers in process of erection in factory of Spreckels Sugar Co., Spreckels, Calif. The largest Beet Sugar Factory in the world.

Mulhouse, showed an average of at least 5 per cent.; Zeuner sets it down as approximately from 7½ to 15 per cent.; the careful experiments at the American Institute in 1871 show in cylindrical tubulars 7.9 per cent., and in the tests at the Centennial Exposition one boiler showed as high as 18.57 per cent. priming.

In sixteen different tests of the dryness of the steam from Babcock & Wilcox boilers made by ten different engineers, the average moisture in the steam was only 0.82 per cent. The highest was 4.16 per cent., which was less than the same engineer with the same apparatus found in large two-flue boilers, working very lightly.



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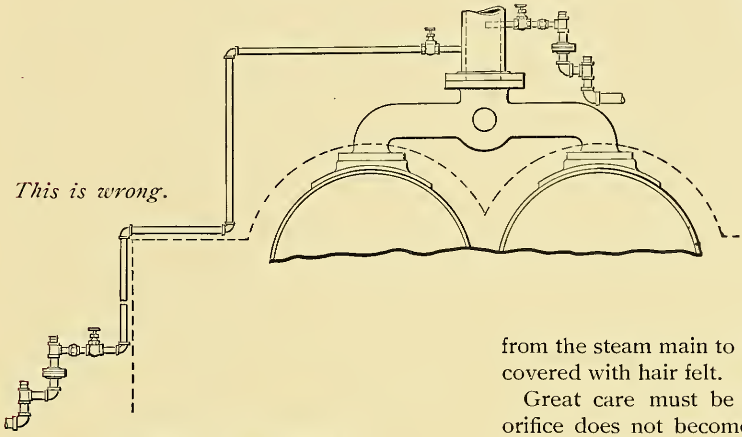

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TESTS FOR MOISTURE.

In boiler trials it is essential to know the quality of the steam generated: whether it is wet, dry, or superheated. For many years the standard apparatus for ascertaining this was the barrel calorimeter (see p. 111), but this has, of late, been superseded by the throttling calorimeter, an instrument first devised by Prof. C. H. Peabody of the Massachusetts Institute of Technology (see Journal of Franklin Institute, August, 1888), and which, when properly handled, and connected, gives results far more accurate than can be obtained in any other way.

There have been numerous forms of this instrument, one of the simplest being that designed by Mr. George H. Barrus, of Boston, which is described below: —

Steam is taken from a ½ inch pipe provided with a valve and passes through two ¾ inch tees situated on opposite sides of a ¾ inch flange union, substantially as shown in the accompanying sketch. A thermometer cup, or well, is screwed into each of these tees, and a piece of sheet iron perforated with a ⅛ inch hole in the center is inserted between the flanges and made tight with rubber or asbestos gaskets, which also act as non-conductors of heat. For convenience a union is placed near the valve as shown, and the exhaust steam may be led away by a *short* 1¼ inch pipe, shown by dotted lines. The thermometer wells are filled with mercury or heavy cylinder oil, and the whole instrument from the steam main to the 1¼ inch pipe is well covered with hair felt.

Great care must be taken that the ⅛ inch orifice does not become choked with dirt, and that no leaks occur, especially at the sheet iron disc, also that the exhaust pipe does not produce any back pressure below the flange. Place a thermometer in each cup, and, opening the ½ inch valve wide, let steam flow through the instrument for ten or fifteen minutes; then take frequent readings on the two thermometers and the boiler gauge, say at intervals of one minute.

The throttling calorimeter depends on the principle that dry steam when expanded from a higher to a lower pressure without doing external work becomes superheated, the amount of superheat depending on the two pressures. If, however, some moisture be present in the steam, this must necessarily be first evaporated, and the superheating will be proportionately less. The limit of the instrument is reached when the moisture present is sufficient to prevent any superheating.

Assuming that there is no back pressure in the exhaust, and that there is no loss of heat in passing through the instrument, the total heat in the mixture of steam and moisture before throttling, and in the superheated steam after

Washington Life Insurance Company Building, New York. 675 H.P. Babcock & Wilcox Boilers.

throttling, will be the same, and will be expressed by the equation

$$H - \frac{x\,L}{100} = 1146.6 + .48\,(t - 212)$$

$$\text{or} \quad x = \frac{H - 1146.6 - .48\,(t - 212)}{L} \times 100$$

in which x = percentage of moisture; H = total heat above 32° in the steam at boiler pressure; L = latent heat in the steam at boiler pressure; 1146.6 = total heat in the steam at atmospheric pressure; t = temperature shown by lower thermometer of calorimeter; 212 = temperature of dry steam at atmospheric pressure.

Theoretically the boiler pressure is indicated by the temperature of the upper thermometer, but owing to radiation, etc., it is usually too low, and it is better to use the readings of the boiler gauge, if correct, or better still to have a test gauge connected on the ½ inch pipe supplying the calorimeter.

If the instrument be well covered, and there is as little radiating surface as possible, the above assumption that there is no loss of heat in passing through the instrument may be nearly, though never quite, correct. On the other hand it is more than likely to be very far from correct, and, to eliminate any errors of this kind, Mr. Barrus recommends a so-called "calibration" for dry steam. This, again, involves an assumption which is open to some doubt, which is that steam, when in a quiescent state, drops all its moisture and becomes dry. No other practical method, however, has been proposed, and this is, therefore, the only method used at the present time. Some engineers, however, refuse to make any calibration, but, instead, make an assumed allowance for error.

To make the calibration, close the boiler stop valve, which must be on the steam pipe beyond the calorimeter connection. Keep the steam pressure exactly the same as the average pressure during the test, for at least fifteen minutes, taking readings from the two thermometers during the last five minutes. The upper thermometer should read precisely the same as during the test, and the lower thermometer should show a higher temperature; this reading of the *lower* thermometer is the calibration reading for dry steam, which we will call T.

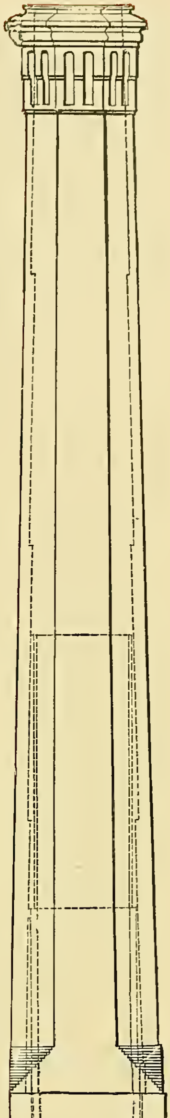
Calculation of results, allowing for radiation, by calibration method:—

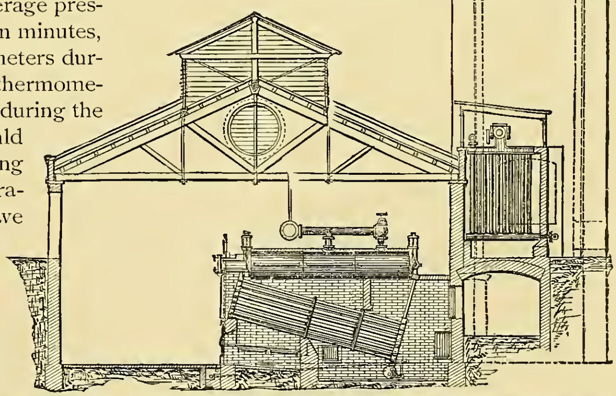
$$\text{Formula} \quad x = \frac{.48\,(T - t)}{L} \times 100$$

in which x = percentage of moisture; T = calibration reading of lower thermometer; t = test reading of lower thermometer; L = latent heat of steam at boiler pressure.

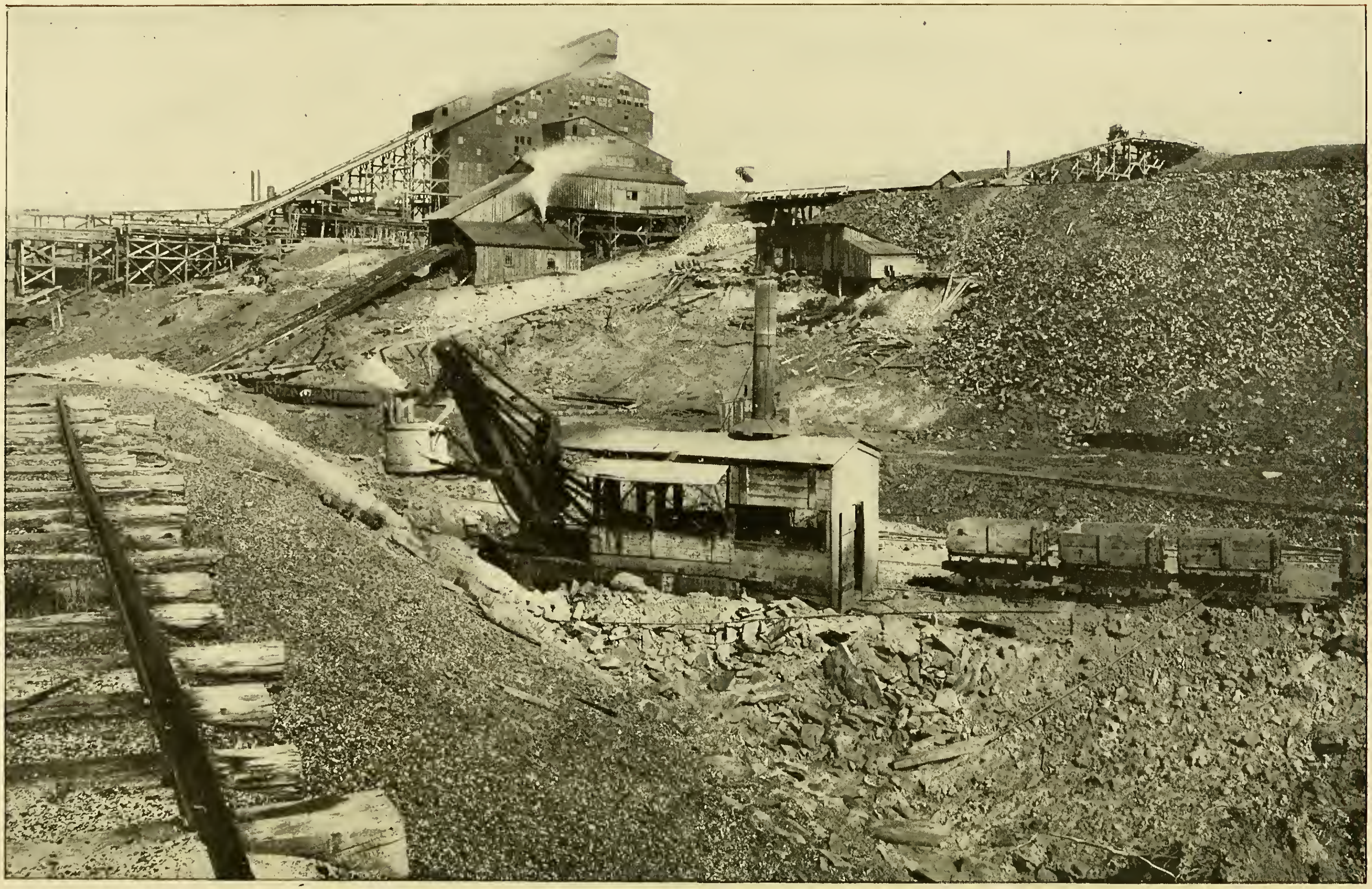
The method of taking a sample of steam from the main is of the greatest importance, and more erroneous results are due to improper connections than to any other cause. The sample should be taken from the main steam current of the steam ascending in a vertical pipe. Avoid perforated and slotted nipples, and use only a plain, open ended nipple projecting far enough into the steam pipe to avoid collecting any condensation that may be on the sides of the pipe. Take care that no pockets exist in the steam main near the calorimeter in which condensation can collect and run down into sampling nipple. Make connections as short as possible.

As mentioned above, there is a limit in the range of the throttling calorimeter which varies from 2.88% at 50 pounds pressure to 7.17% at 250 pounds. When this limit is reached a small separator may be interposed between the steam main and the calorimeter, which will take out the excess of moisture. By weighing the drip from the separator and ascertaining its per-





Boiler House and Chimney for Babcock & Wilcox Boiler with Economizer, etc.



A Colliery of the Lehigh Valley Coal Company. 8800 H. P. Babcock & Wilcox Boilers used by this Company.

centage of the steam flowing through, and adding this to the percentage of moisture then shown by the throttling calorimeter, the total moisture in the steam may be ascertained. It is seldom, however, in a well designed boiler that any but a throttling calorimeter becomes necessary.

RIVETED JOINTS.

The strength of a riveted joint is dependent on—first, the section of plate remaining after deducting the diameter of the rivet holes and—second, on the strength in shear of the rivets.

Let d = diameter of rivet after driving in inches.
a = area of one rivet in square inches.
p = pitch of rivets in inches.
n = number of rows of rivets.
t = thickness of shell in inches.
R = internal radius of drum in inches.
T = tensile strength of plates per square inch in pounds.
S = shearing strength of rivets per square inch in pounds.
f = factor of safety.

Then, to find the strength of a plate between rivets in percentage of the full plate :—

$$(1) \qquad \frac{p-d}{p} = P$$

To find value of the shearing strength of rivet in percentage of plate :—

$$(2) \qquad \frac{a \times n \times S}{p \times t \times T} = P'$$

To find the pressure which a drum with seams designed by the foregoing formulæ will endure, select the smaller of the results P and P' obtained by formulæ 1 and 2, and designate this as V. Then

$$\frac{t \times T \times V}{R \times f} = \text{pounds per sq. in. internal pressure.}$$

In designing joints with two cover plates at least a part of the rows of rivets will be in double shear. A rivet in double shear is generally considered as 1.75 times its value in single shear. Take this into consideration in counting up the number of rows of rivets for such joints.

A joint may be highly efficient in strength and fail to be tight. The tightness of a joint depends on the rivet spacing and the thickness of the caulking edge. For this reason a cover plate thicker than is required for strength can be used with good results.

FEEDING BOILERS.

The relative value of injectors, direct-acting steam pumps, and pumps driven from the engine, is a question of importance to all steam users. The following table has been calculated by D. S. Jacobus, M. E., from data obtained by experiment. It will be noticed that when feeding cold water direct to boilers, the injector has a slight economy, but when feeding through a heater a pump is much the most economical.

Method of Supplying Feed-Water to Boiler. Temperature of feed-water as delivered to the pump or to the injector, 60° Fah. Rate of evaporation of boiler, 10 pounds of water per pound of coal from and at 212° Fah.	Relative amount of coal required per unit of time, the amount for a direct acting pump, feeding water at 60°, without a heater, being taken as unity.	Saving of fuel over the amount required when the boiler is fed by a direct acting pump without heater.
Direct acting pump feeding water at 60°, without a heater, ...	1.000	.0
Injector feeding water at 150°, without a heater, .	.985	1.5 per cent.
Injector feeding through a heater in which the water is heated from 150 to 200°,	.938	6.2 per cent.
Direct acting pump feeding water through a heater, in which it is heated from 60 to 200°, ...	.879	12.1 per cent.
Geared pump, run from the engine, feeding water through a heater, in which it is heated from 60 to 200°,	.868	13.2 per cent.

ECONOMY OF HIGH PRESSURE STEAM.

Higher steam pressure is the tendency of the times, and with good reason, for the higher the pressure the greater the opportunity for economy in generating power. The compound and triple expansion engines of the present day, which have reduced the cost of power some 40 per cent. over the best performance of a few years ago, require higher pressure than can with safety be carried on shell boilers, but there is no difficulty in carrying any desirable pressure on a sectional water-tube boiler properly constructed. Babcock & Wilcox boilers, in special cases, carry as high as 500 pounds pressure in regular work.

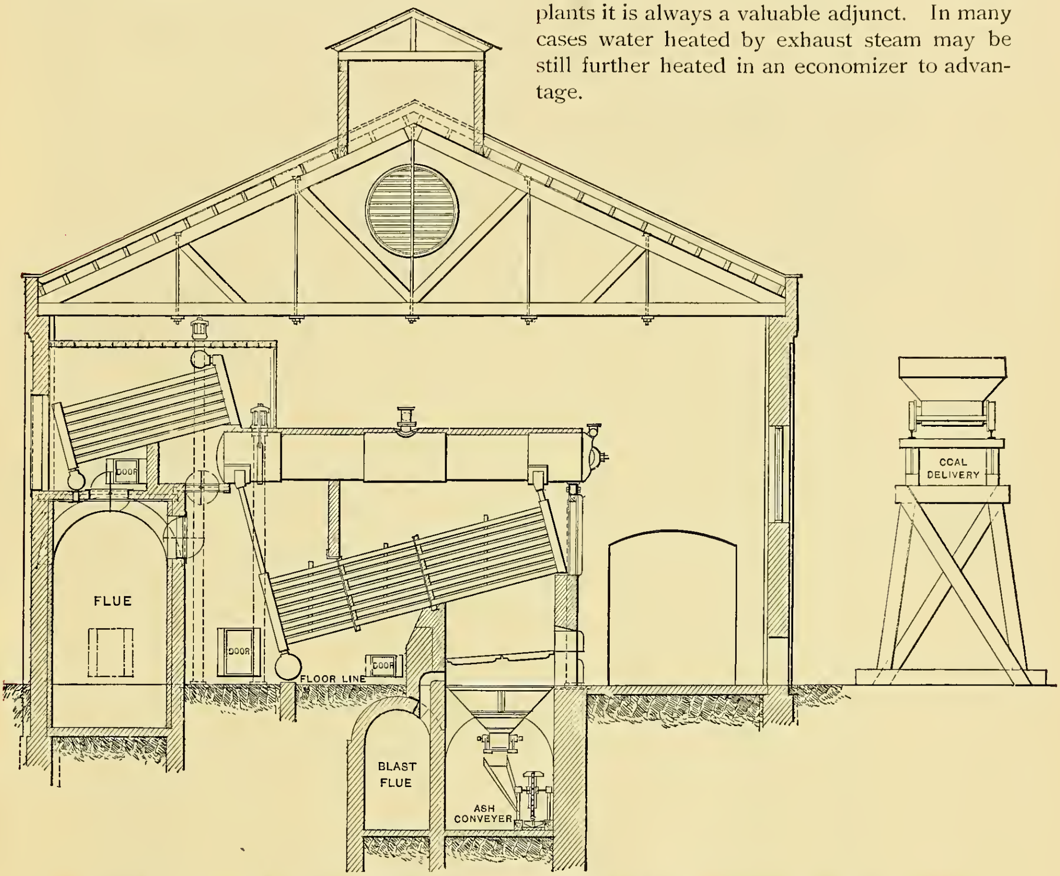
HEATING FEED-WATER.

The feed-water furnished to steam boilers has to be heated from the normal temperature to that of the steam before evaporation can commence, and this generally at the expense of the fuel which should be utilized in making steam. This temperature at 75 lb. pressure is 320°, and if we take 60° as the average temperature of feed, we have 260 units of heat per pound, which, as it takes 1.151 units to evaporate a pound from 60°, represents 22.5 per cent. of the fuel. All of this heat, therefore, which can be imparted to the feed-water is just so much saved, not only in cost of fuel, but in capacity of boiler. But it is essential that it be done by heat which would otherwise be wasted. All heat imparted to feed-water by injectors and "live-steam heaters" comes from the fuel and represents no saving.

New York City Hall. The three buildings in the background contain 1,596 H.P. Babcock & Wilcox Boilers.

There are two sources of waste heat available for this purpose — exhaust steam and chimney gases. By the former, water may be heated to 200°, or possibly to 210°, in a well-proportioned heater.

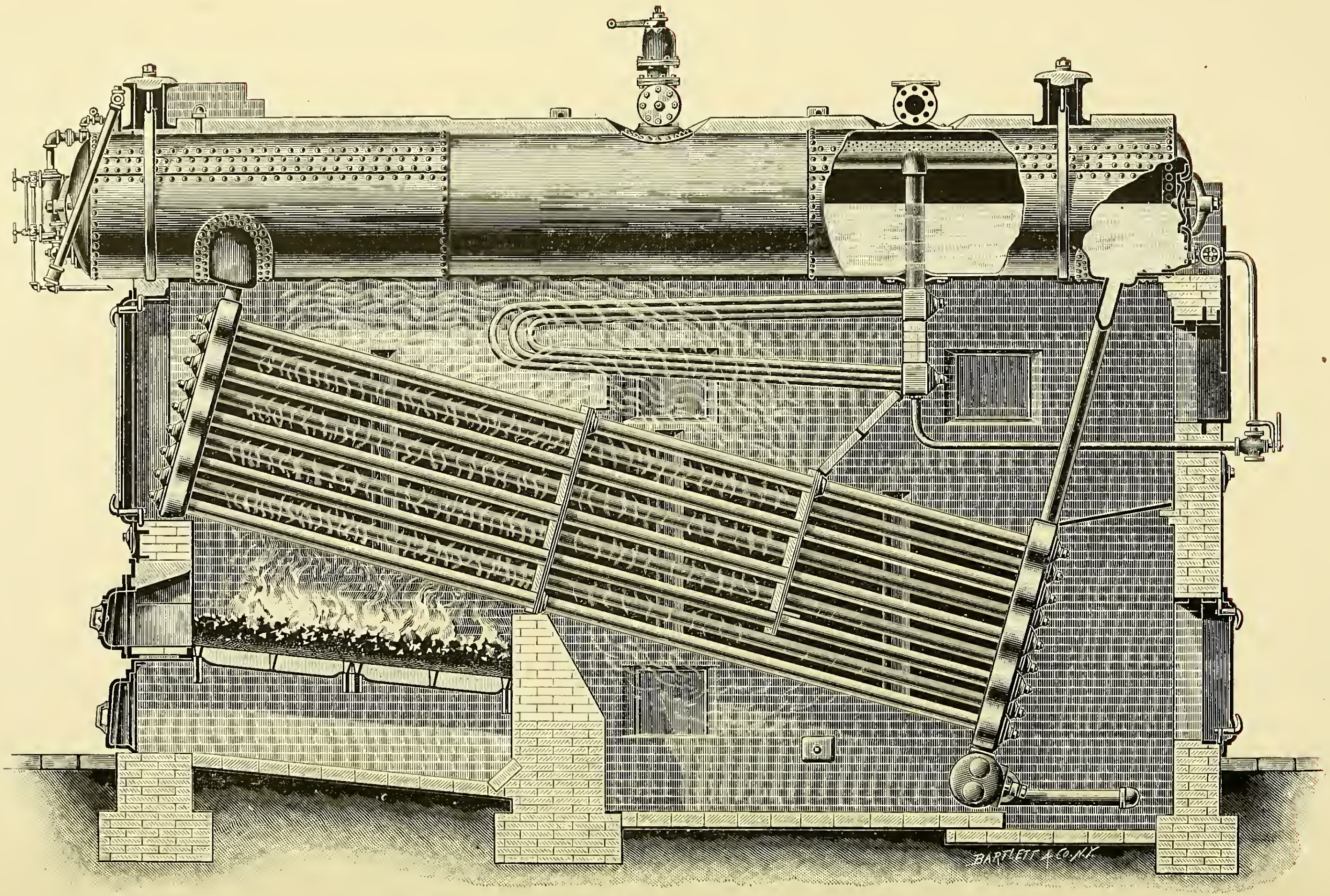
The gases going to the chimney carry off on an average, according to good authority, 51 per cent. of the fuel, and in the most economical boiler this cannot be reduced below 12 per cent. Some proportion of this is always available for heating the feed-water, by what are known as "economizers," and frequently it may be carried nearly to the temperature of high pressure steam, making a saving in some instances of 20 per cent. The more wasteful the boiler, the greater the benefit of the economizer; but for large plants it is always a valuable adjunct. In many cases water heated by exhaust steam may be still further heated in an economizer to advantage.



Babcock & Wilcox Boilers at Solvay Process Co.'s, 3,264 H.P., set with Independent Feed-Water Heaters. 20,154 H.P. now in use.

SAVING OF FUEL BY HEATING FEED-WATER. (IN PER CENT., STEAM AT 60 POUNDS.)

Initial Temperature of Water.	Final Temperature of Feed-Water.							Initial Temperature of Water.	Final Temperature of Feed-Water.						
	120	140	160	180	200	250	300		120	140	160	180	200	250	300
32°	7.50	9.20	10.90	12.36	14.30	19.03	22.90	90°	2.68	4.47	6.26	8.06	9.85	14.32	18.81
35	7.25	8.96	10.66	12.09	14.09	18.34	22.60	95	2.24	4.04	5.84	7.65	9.44	13.94	18.44
40	6.85	8.57	10.28	12.00	13.71	17.99	22.27	100	1.80	3.61	5.42	7.23	9.03	13.55	18.07
45	6.45	8.17	9.90	11.61	13.34	17.64	21.94	110	.90	2.73	4.55	6.38	8.20	12.76	17.28
50	6.05	7.71	9.50	11.23	13.00	17.28	21.61	120	0	1.84	3.67	5.52	7.36	11.95	16.49
55	5.64	7.37	9.06	10.85	13.60	16.93	21.27	130	....	.92	2.77	4.64	6.99	11.14	15.24
60	5.23	6.97	8.72	10.46	12.20	16.58	20.92	140	....	0	1.87	3.75	5.62	10.31	14.99
65	4.82	6.56	8.32	10.07	11.82	16.20	20.58	150	....	....	.94	2.83	4.72	9.46	14.18
70	4.40	6.15	7.91	9.68	11.43	15.83	20.23	160	....	....	0	1.91	3.82	8.59	13.37
75	3.98	5.74	7.50	9.28	11.04	15.46	19.88	170	....	....	....	.96	2.89	7.71	12.54
80	3.55	5.32	7.09	8.87	10.65	15.08	19.52	180	....	....	....	0	1.96	6.81	11.70
85	3.12	4.90	6.63	8.46	10.25	14.70	19.17	200	....	....	....	....	0	4.85	9.93



Side View of Babcock & Wilcox Boiler with Patent Superheater.

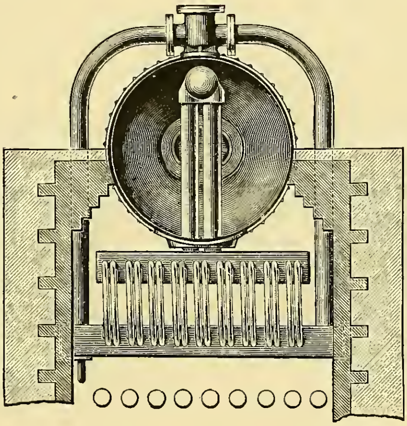
SUPERHEATED STEAM.

Steam which has a higher temperature than that normal to its pressure is termed "superheated" or "gaseous."

Of the sources of waste in an engine, the condensation of steam from the cooling effects of the cylinder walls, or cylinder condensation as it is called, is by far the greatest. This was recognized even early in the present century, but in 1855, for the first time, the extent of this loss was established in a definite manner, by Hirn. In more recent years, Professor Dwelshauvers-Dery, Mr. Walther Meunier, of the Alsatian Association of Steam Users, Professor William C. Unwin, and others, have given much of their time and thought to this question.

It has been established, practically, that in an ordinary single cylinder non-condensing engine, the amount of waste through cylinder condensation amounts, with an early cut-off, to 35 to 40 per cent. of the total steam used.

The best means of partially or wholly preventing this loss is by the use of superheated steam.



Steam is said to be superheated when, at any given boiler pressure, it has a higher temperature than the water from which it was evaporated.

Water, no matter from what cause arising, cannot exist in the presence of superheated steam; it robs the steam of its extra heat, and is itself evaporated into steam.

The temperature of saturated steam cannot be raised without increasing its pressure; but the temperature of superheated steam allowed to expand can be raised without increasing the pressure. Expansion is provided for by the steam being drawn off and used, or, if no steam is used, by the safety valve lifting. We mention this to prevent any erroneous impression that superheating steam causes the production of excessive pressures in boilers, and consequently entails more danger in ordinary working.

From time to time various attempts have been made to supply superheated steam to engines, both on land and on board ship. In the latter connection, Mr. John Penn, the famous engineer, made many trials, and stated, in his papers read before the Institution of Mechanical Engineers in 1859–1860, that with 100° to 120° F. of superheat, an economy of 20 to 30 per cent. in fuel consumption was obtained on some of the steamers in which superheating was adopted.

At that time the application of superheaters was spasmodic, due to mechanical defects in the superheaters themselves or in their application. They were frequently placed in the uptakes of marine boilers, where they were not sufficiently protected from the corrosive action of the gases condensed after leaving the boilers, In other instances the inaccessibility of their position caused them to incur disfavor, and the lack of suitable oils for engine cylinder lubrication increased the difficulties.

The "rationale" of the use of superheated steam is not only the prevention of loss through condensation in steam pipes, but the addition of such an amount of superheat to the steam, before it enters the cylinder, as will make up for that robbed by the cylinder walls, so that the steam will remain practically dry, at all events up to the point of cut-off.

Bearing in mind what has already been done, we find that the principles on which a superheater should be constructed, to give a sufficiently high temperature, are:—

First.—The necessity of placing the superheater in a position where a suitable temperature is available. If a boiler is working under economical conditions, the difference between the temperature of saturated steam and of the escaping flue gases leaving a boiler is not sufficient to superheat the steam produced, unless the surface of the superheater be very large: hence, generally speaking, a superheater should not be placed in the flue between boiler and chimney. On the other hand, if placed too near to the boiler furnace, or in a separate furnace, considerable temperature fluctuations may occur, and possibly an excessive temperature may be attained which would cause damage.

Secondly.—The superheater should be constructed to admit of all its parts expanding and contracting freely, without severe strains being put on any of the joints, which might cause them to leak; flanged joints, when exposed to furnace gases, should be avoided wherever possible.

Thirdly.—Provision should be made to protect the superheater against overheating when steam is not passing through it sufficiently to carry away the heat supplied by the furnace gases.

It will be seen from the illustration that the Patent Superheater fulfills all these conditions. It is placed in a position where there is practically no deteriorating condensation of the gases, and where the temperature is sufficiently high to insure the steam receiving from 100° to 150° F. of superheat.

This superheater is not subject to the immediate action of the fire, as the furnace gases must first pass through the front part of the boiler, which comprises a considerable heating surface. Assuming the boiler to be in regular work, and the firing even, no great fluctuations in temperature can take place where the superheater is fixed. Moreover, it is readily accessible for examination, and for the renewal of tubes.

There are no flanged joints, all the tube joints are expanded.

Freedom for expansion is provided for by the tubes being free at one end, and by the manifolds not being rigidly connected with each other.

Prevention against overheating during steam raising is insured by the arrangement for flooding with boiler water, and using the superheater as part of the boiler heating surface, whilst steam is being raised, or when it is desired to use saturated steam.

As will be seen, the tubes are bent into a "**U**" shape, and connected at both ends with manifolds, one of which receives the natural steam from the boiler, the other collecting the superheated steam after it has traversed the superheater tubes, and delivering it to the valve, placed above the boiler.

The flooding arrangement consists merely in a connection with the water space of the boiler drum, and a three-way cock, by which, at will, the water enters the lower manifold and fills the superheater to the boiler water level. Any steam formed in the superheater tubes is returned into the boiler drum, through the collecting pipe, which, when the superheater is at work, conveys saturated or natural steam into the upper manifold. Prior to opening the superheater stop valve and using superheated steam, the water is drained away from the manifolds by the flooding pipe.

The water in the boiler steam and water drum is, by reason of the fact that it is heated to steam temperature, deprived of its impurities, hence there is no fear, in flooding the superheater with the boiler water, of the superheater tubes becoming incrustated to any detrimental extent.

A considerable number of these superheaters have now been at work for some time, and the results lead to the expectation that their durability will leave nothing to be desired.

From 100° to 150° F. of superheat is usually provided for in the proportion of superheating surface to boiler heating surface adopted, and it has been found by experiment that even with the most refined triple expansion engines, working under ordinary conditions, an economy of from 10 to 15 per cent. can be regularly obtained. With engines less refined, or of slower piston speed, of course the percentage of saving is greater.

The use of the superheater goes a long way to assist engineers to fulfill the task of the present times, namely, to produce a horsepower with a pound of coal.

Professor R. H. Thurston, in a recent paper before the American Society of Mechanical Engineers, on Superheated Steam, arrives at the following conclusions: —

1. Superheated steam, as hitherto employed in the steam engine, has absolutely no thermodynamic value, that is, it neither raises the upper limit of temperature or depresses the lower limit.

2. Superheating has for its sole purpose and result, in the steam engine to-day, the extinction or reduction of the internal thermal wastes of the engine, consequent upon the phenomenon known as initial or "cylinder condensation." Here it is extraordinarily effective, and a small quantity of heat expended in superheating the entering steam effects a comparatively large reduction in the expenditure of steam in the engine.

3. Superheating is superior to any other known means of reduction of internal waste.

4. No trouble need now be found at the engine with sufficient superheating under usual conditions of operation, to annihilate cylinder condensation.

5. The more wasteful the engine, the larger the promise of gain by superheating, and small engines will profit by it more than large, slow engines more than fast, and single engines more than the multiple-cylinder systems.

6. The larger the waste to be checked in the engine, the farther should the superheating be carried.

INCRUSTATION AND SCALE.

Nearly all waters contain foreign substances in greater or less degree, and, though this may be a small amount in each gallon, it becomes of importance where large quantities are evaporated. For instance, a 100 H. P. boiler evaporates 30,000 pounds water in ten hours, or 390 *tons* per month; in the comparatively pure Croton water there would be 88 pounds of solid matter in that quantity, and in many kinds of spring water as much as 2,000 pounds.

The nature and hardness of the scale formed of this matter will depend upon the kind of substances held in solution and suspension. Analyses of a great variety of incrustations show that carbonate and sulphate of lime form the larger part of all ordinary scale, that from carbonate being soft and granular, and that from sulphate hard and crystalline. Organic substances in connection with carbonate of lime will also make a hard and troublesome scale.

The presence of scale or sediment in a boiler results in loss of fuel, burning and cracking of the boiler, predisposes to explosion, and leads to extensive repairs. It is estimated that the presence of $\frac{1}{16}$ inch of scale causes a loss of 13 per cent. of fuel, ¼ inch 38 per cent., and ½ inch 60 per cent. The Railway Master Mechanics' Association of the U. S. estimates that the loss of fuel, extra repairs, etc., due to incrustation, amount to an average of $750 per annum for every locomotive in the Middle and Western States, and it must be nearly the same for the same power in stationary boilers.

The most common and important minerals in boiler scale are carbonate of lime, sulphate of lime, and carbonate of magnesia. Small amounts of alumina and silica are sometimes found, and an oxide of iron not infrequently is present as a coloring matter.

Means of Prevention.

It is absolutely essential to the successful use of any boiler, except in pure water, that it be accessible for the removal of scale, for though a rapid circulation of water will delay the deposit, and certain chemicals will change its character, yet the most certain cure is periodical inspection and mechanical cleaning. This may, however, be rendered less frequently necessary, and the use of very bad water more practical, by the employment of some preventives. The following are a fair sample of those in use, with their results:—

M. Bidard's observations show that "anti-incrustators" containing organic matter help rather than hinder incrustations, and are therefore to be avoided.

Oak, hemlock, and other barks and woods, sumac, catechu, logwood, etc., are effective in waters containing carbonates of lime or magnesia, by reason of their tannic acid, but are injurious to the iron, and not to be recommended.

Molasses, cane juice, vinegar, fruits, distillery slops, etc., have been used with success so far as scale is concerned, by reason of the acetic acid which they contain, but this is even more injurious to the iron than tannic acid, while the organic matter forms a scale with sulphate of lime when it is present.

Milk of lime and metallic zinc have been used with success in waters charged with bicarbonate of lime, reducing the bicarbonate to the insoluble carbonate.

Barium chloride and milk of lime are said to be used with good effect at Krupp's Works, in Prussia, for waters impregnated with gypsum.

Soda ash and other alkalies are very useful in waters containing sulphate of lime, by converting it into a carbonate, and so forming a soft scale easily cleaned. But when used in excess they cause foaming, particularly where there is oil coming from the engine, with which they form soap. All soapy substances are objectionable for the same reason.

Petroleum has been much used of late years. It acts best in waters in which sulphate of lime predominates. As crude petroleum, however, sometimes helps in forming a very injurious crust, the refined only should be used.

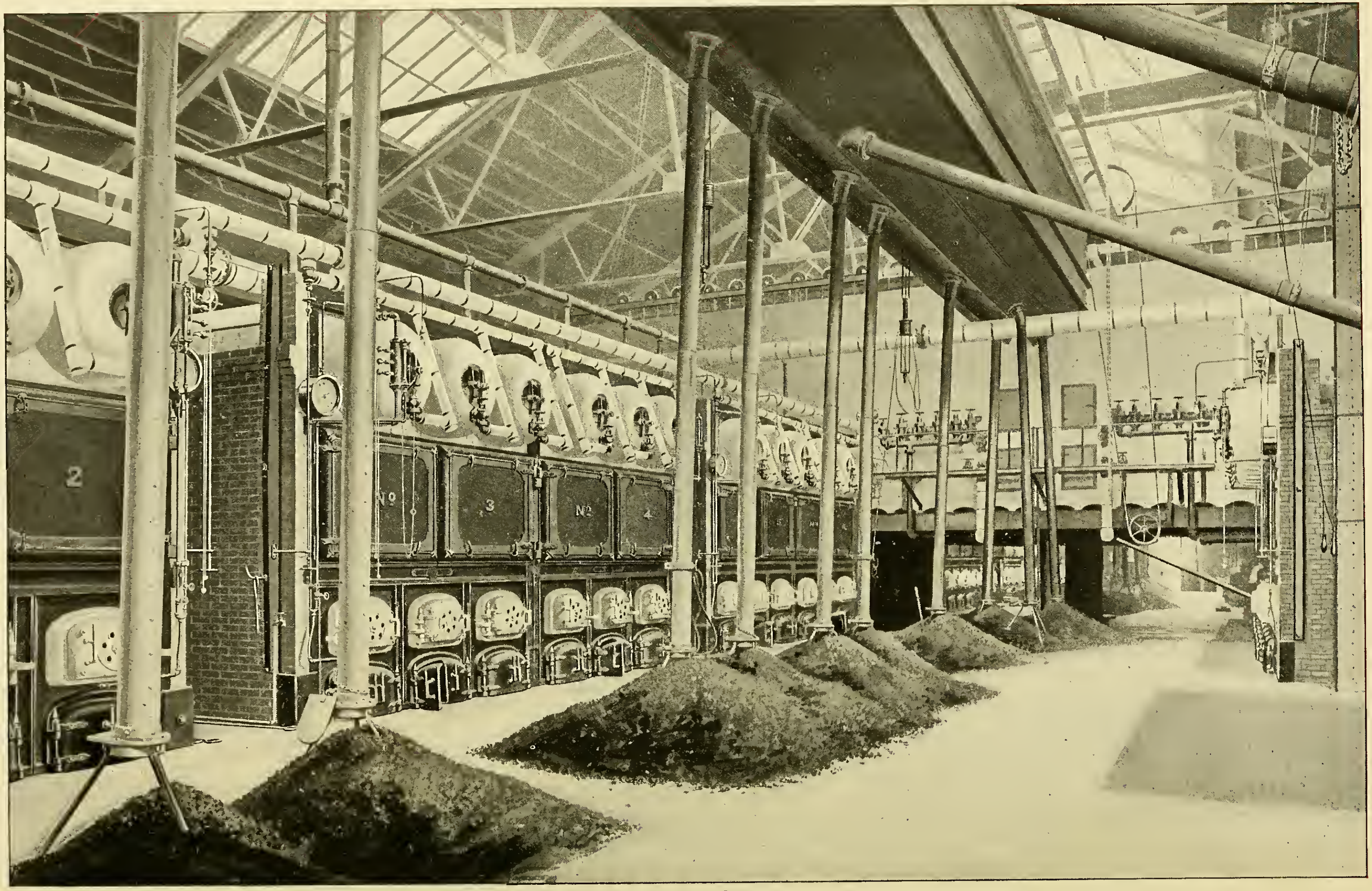
Tannate of soda is a good preparation for general use, but, in waters containing much sulphate, it should be supplemented by a portion of carbonate of soda or soda ash.

A decoction from the leaves of the eucalyptus is found to work well in some waters, in California.

For muddy water, particularly if it contain salts of lime, no preventive of incrustation will prevail except filtration, and in almost every instance the use of a filter, either alone or in connection with some means of precipitating the solid matter from solution, will be found very desirable.

In all cases where impure or hard waters are used, frequent "blowing" from the mud-drum is necessary to carry off the accumulated matter, which if allowed to remain would form scale.

When boilers are coated with a hard scale difficult to remove, it will be found that the addition of ¼ pound caustic soda per horse-power, and steaming for some hours, according to the thickness of the scale, just before cleaning, will greatly facilitate that operation, rendering the scale soft and loose. This should be done, if possible, when the boilers are not otherwise in use.



Electric Traction Company, Delaware Avenue Power Station, Philadelphia. Pa. 4,000 H.P. Babcock & Wilcox Boilers.

HEATING FROM CENTRAL STATIONS.

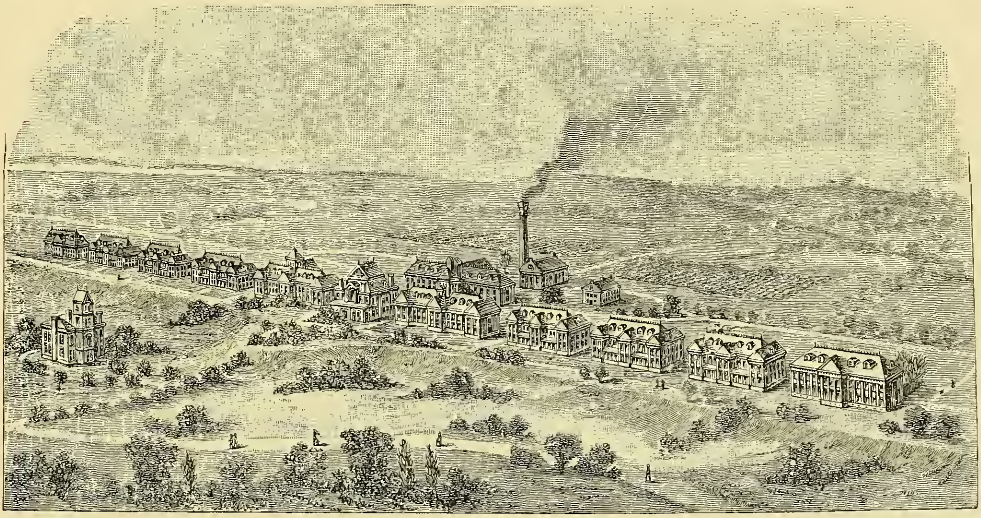
It has been thoroughly demonstrated, by practice, that a number of buildings may be heated from a single central plant, instead of its being necessary to place a boiler in each. This is a simple problem where the buildings form a group, as at Columbia College, in New York city, Cornell University, Ithaca, N. Y., Vanderbilt University, Nashville, Tenn., the Indiana State Asylums for the Insane, and many other similar institutions, where a single plant of Babcock & Wilcox boilers supply heat and power to a number of detached buildings. It has also been attempted in a number of places to carry steam, as gas and water are supplied. Though a number of these attempts have been failures, the experience of the New York Steam Co., the most extensive of such plants yet constructed, has fully demonstrated that it is possible to thus carry steam for miles, with no serious losses, and that private houses and business places may be thus supplied regularly with steam, at reduced cost to them, and at a profit to the producer. This company have, at present, three stations in operation, one of which is doubtless the largest single plant of stationary boilers in the world, — 12,000 H. P., under one roof,— supplying steam through seventeen miles of pipe, laid in the streets.

In a work of this magnitude it becomes absolutely imperative that the boilers which furnish the steam should be of such a construction as to give the greatest amount of useful effect for the coal burned, and at the same time be able to run continuously, with a minimum amount of stoppage for repairs; and, above all, they should be so constructed as to be safe against destructive explosion. The ability to furnish dry steam is also a very important point, where it is intended to carry it through so many miles of pipe before it is finally used up. The boiler adopted was the Babcock & Wilcox Water-tube Boiler.

HEATING BY STEAM.

In heating buildings by steam, the amount of boiler and heating pipe depends largely on the kind of building and its location. Wooden buildings require more than stone, and stone more than brick. Iron fronts require still more, and glass in windows demands twenty times as much heat as the same surface in brick walls. Also if the heating be done by indirect radiation from 50 to 100 per cent. more surface will be required than when direct radiation is used. No rules can be given which will not require a liberal application of "the co-efficient of common sense."

Radiating surface may be calculated by the rule: *Add together the square feet of glass in the windows, the number of cubic feet of air required to be changed per minute, and one-twentieth the surface of external wall and roof; multiply this sum by the difference between the required temperature of the room and that of the external air at its lowest point, and divide the product by the difference in temperature between the steam in the pipes and the required temperature of the room.* The quotient is the required radiating surface in square feet. Each



Northern Hospital for the Insane, Logansport, Ind., with 400 H.P. of Babcock & Wilcox Boilers. Erected 1885.

Waldorf-Astoria Hotel, New York. 2257 H.P. Babcock & Wilcox Boilers.

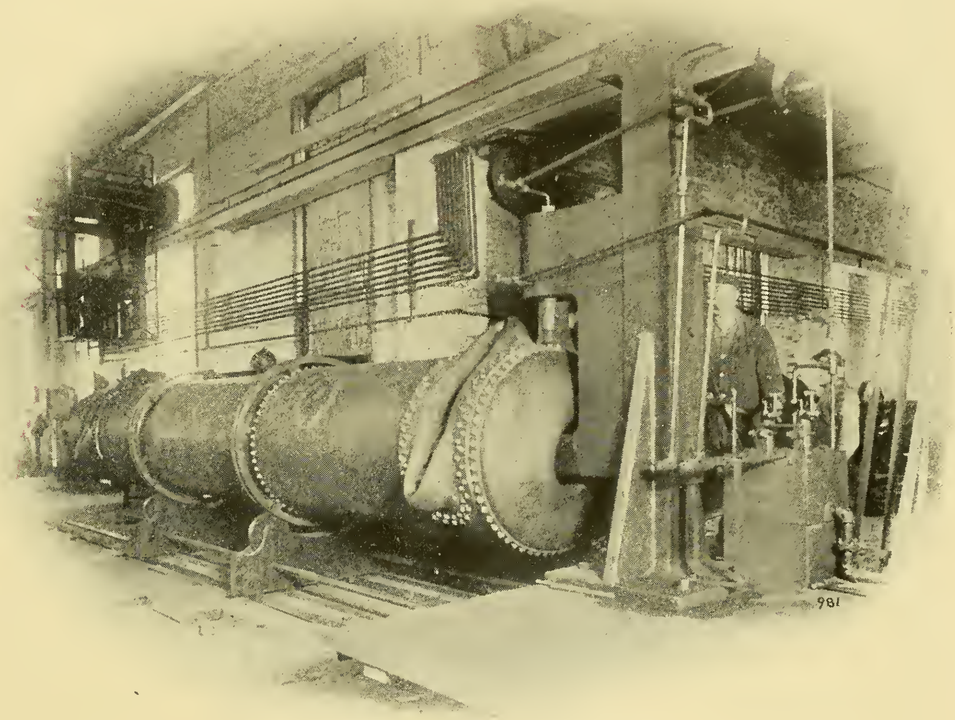
square foot of radiating surface may be depended upon in average practice to give out three heat units per hour for each degree of difference in temperature between the steam inside and the air outside, the range under different conditions being about 50 per cent. above or below that figure. In *indirect* heating, the efficiency of the radiating surface will increase, and the temperature of the air will diminish, when the quantity of the air caused to pass through the coil increases. Thus one square foot radiating surface, with steam at 212°, has been found to heat 100 cubic feet of air per hour from zero to 150°, or 300 cubic feet from zero to 100° in the same time.

The best results are attained by using indirect radiation to supply the necessary ventilation, and direct radiation for the balance of the heat. The best place for a radiator in a room is beneath a window. Heated air cannot be made to enter a room unless means are provided for permitting an equal amount to escape. The best place for such exit openings is near the floor.

Small pipes are more effective than large. When the diameter is doubled, 20 per cent. additional surface should be allowed, and for three times the diameter, 30 per cent. additional is required. For indirect radiation that surface is most efficient which secures the most intimate contact of the current of air with the heated surface. Rooms on windward side of house require more radiating surface than those on sheltered side.

Where the condensed water is returned to the boiler, or where low pressure of steam is used, the diameter of mains leading from the boiler to the radiating surface should be equal, in inches, to *one-tenth the square root of the radiating surface, mains included*, in square feet. Thus a 1 inch pipe will supply 100 square feet of surface, itself included. Return pipes should be at least ¾ inches in diameter, and never less than one-half the diameter of the main — longer returns requiring larger pipe. A thorough drainage of steam pipes will effectually prevent all cracking and pounding noises therein.

The amount of air required for ventilation is from 4 to 16 cubic feet per minute for each person, the larger amount being for prisons and hos-



Riveting Drum Heads at Babcock & Wilcox Shop.

Roman Catholic Protectory, Flatlands, Pa. 450 H.P. Babcock & Wilcox Boilers.

pitals. From ½ to 1 cubic foot per minute should be allowed for each lamp or gas burner employed.

One square foot of boiler surface will supply from 7 to 10 square feet of radiating surface, depending upon the size of boiler and the efficiency of its surface, as well as that of the radiating surface. Small boilers for house use should be much larger proportionately than large plants. Each horse-power of boiler will supply from 240 to 360 feet of 1-inch steam pipe, or from 80 to 120 square feet of radiating surface.

Cubic feet of space has little to do with amount of steam or surface required, but is a convenient factor for rough calculations. Under ordinary conditions one horse-power will heat, approximately, in

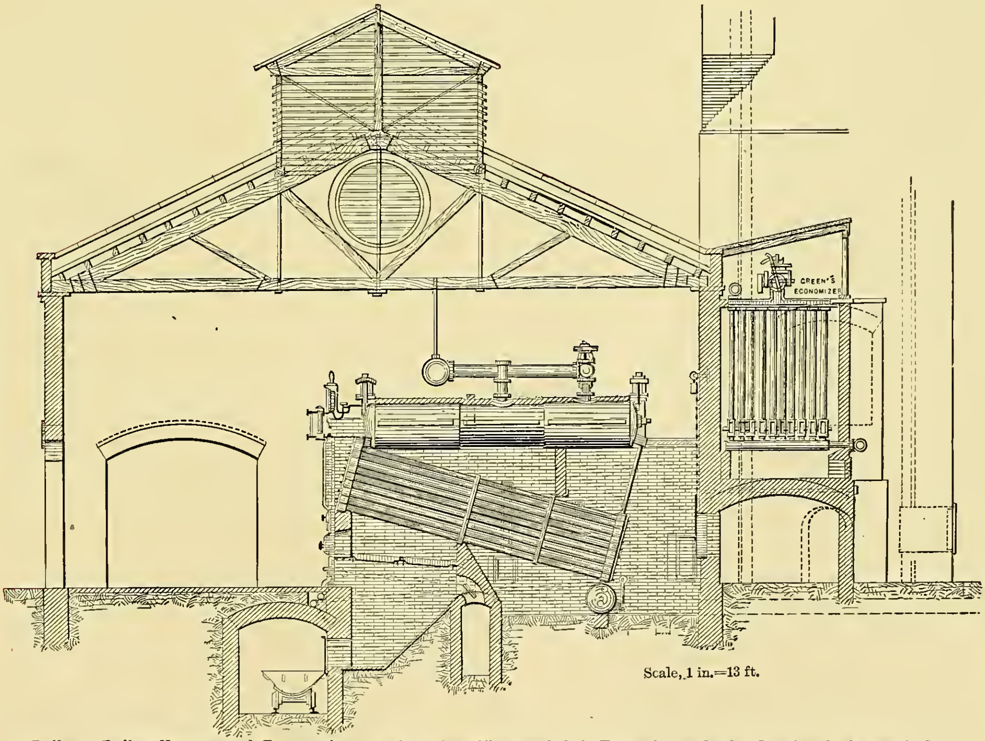
Brick dwellings, in blocks, as in cities,	15,000 to 20,000 cub.ft.
Brick stores, in blocks, ...	10,000 to 15,000 cub.ft.
Brick dwellings, exposed all round, .	10,000 to 15,000 cub.ft.
Brick mills, shops, factories, etc., . .	7,000 to 10,000 cub.ft.
Wooden dwellings, exposed, . . .	7,000 to 10,000 cub.ft.
Foundries and wooden shops, . . .	6,000 to 10,000 cub.ft.
Exhibition buildings, largely glass, etc.,	4,000 to 15,000 cub.ft.

The system of heating mills and manufactories by means of pipes placed overhead, is being largely adopted, and is recommended by the Boston Manufacturers' Mutual Fire Ins. Co. in preference to radiators near the floor, particularly for rooms in which there are shafting and belting to circulate the air.

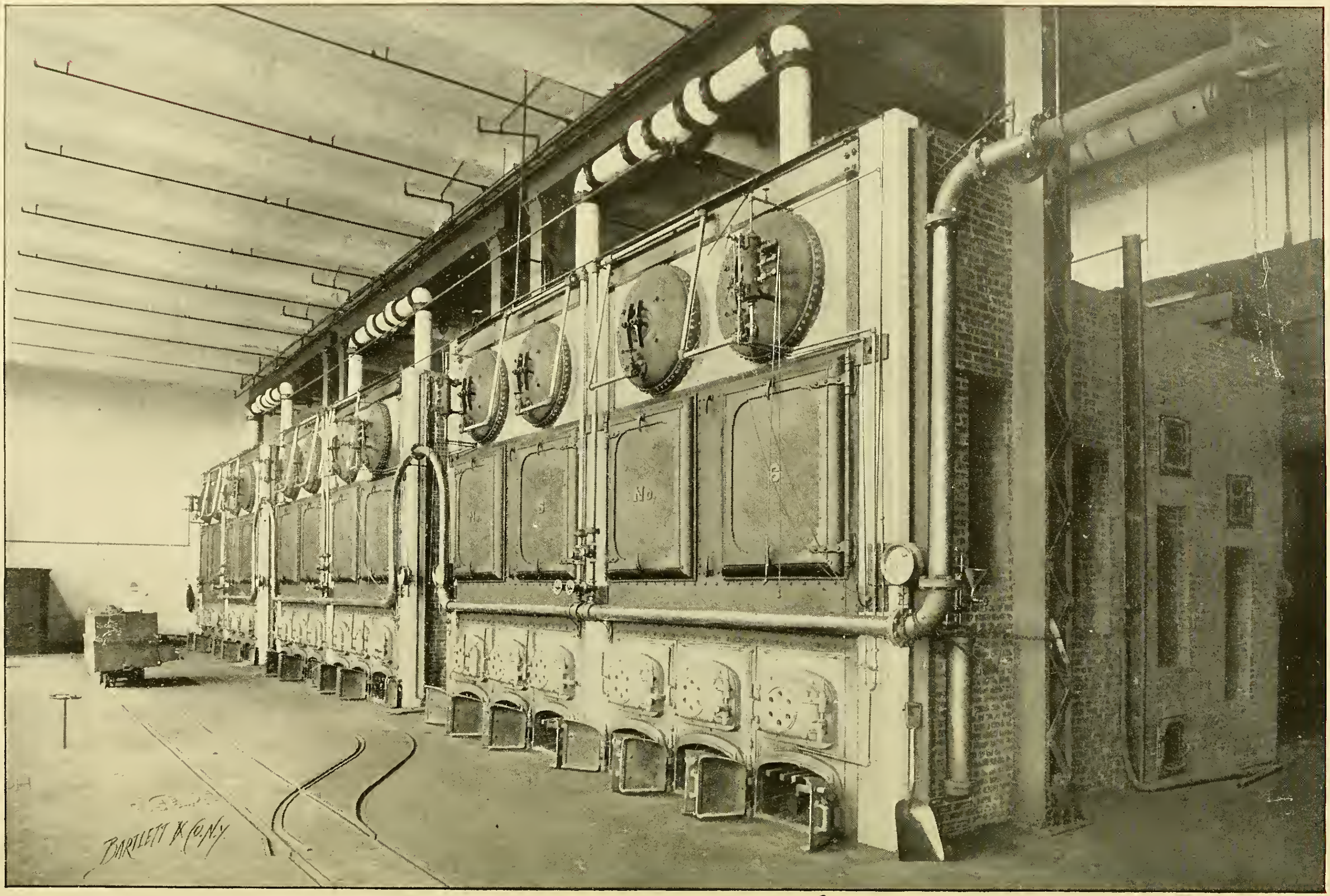
In heating buildings care should be taken to supply the necessary moisture to keep the air from becoming "dry" and uncomfortable. The capacity of air for moisture rises rapidly as it is heated, it being four times as great at 72° as at 32°. For comfort, air should be kept at about "50 per cent. saturated." This would require one pound of vapor to be added to each 2,500 cubic feet heated from 32° to 70°.

A much needed attachment has recently been introduced, which acts automatically upon the steam valves of the radiators, or upon the hot air registers and ventilators, and maintains the temperature in a room to within one-half a degree of any standard desire.

A "separator" acting by centrifugal force has been recently tested, and is very efficient, in trapping out all the water entrained in steam. It will be found valuable, particularly where the steam has to be carried a long distance from the boiler, and for the purpose of preventing "hammering" of water in the pipes.



Boilers, Boiler House, and Economizers, with Blast Flue and Ash Tunnel, made for Lombard, Ayres & Co., Seaboard Oil Refinery, Bayonne, N. J. 15 orders, 2,246 H.P.

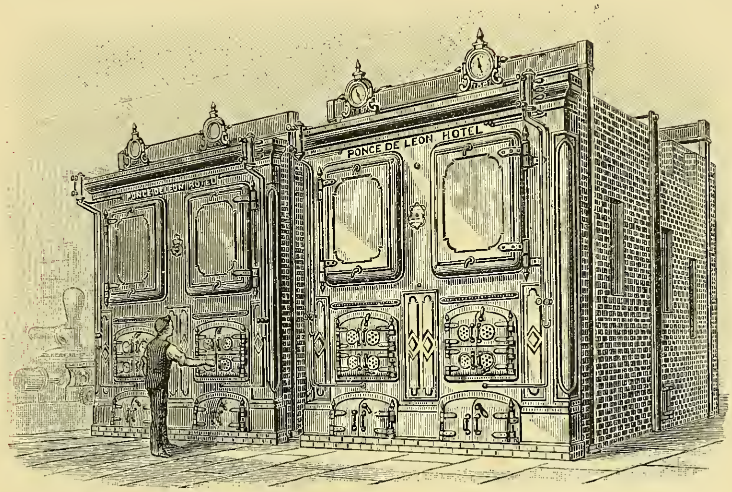


1920 H. P. Babcock & Wilcox Boilers in Boott Cotton Mills, Lowell, Mass.

HEATING LIQUIDS AND BOILING BY STEAM.

(*a.*) Efficiency of surface, where all the air is expelled. For vertical surface, each square foot will transmit 230 heat units per hour, for each degree of difference in the temperature of the two sides. For horizontal and inclined surface, each square foot will transmit 330 heat units per hour for each degree of difference in temperature between the two sides.

(*b.*) Steam required. Each 966 heat units will require the condensation of one pound of steam at 212° or 1,000 units at 75 lbs. pressure.



416 H. P. Babcock & Wilcox Boilers in Ponce de Leon Hotel, St. Augustine, Fla.

Each pound of steam condensed will evaporate one pound of water (nearly) from the temperature of evaporation. Each horse-power of boiler will heat 30,000 lbs. water 1° per hour, or evaporate 30 lbs. water in the same time.

DRYING BY STEAM.

There are three modes of drying by steam. 1st. By bringing wet substances in direct contact with steam-heated surfaces, as by passing cloth or paper over steam-heated cylinders, or clamping veneers between steam-heated plates. 2d. By radiated heat from steam pipes, as in some lumber kilns, and laundry drying rooms. 3d. By causing steam-heated air to pass over wet surfaces, as in glue works, etc.

The second is rarely used except in combination with the third. The first is the most economical, the second less so, and the third least. Under favorable circumstances, it may be estimated that one horse-power of steam will evaporate 24 pounds water by the first method, 20 by the second, and 15 by the third.

The philosophy of drying or evaporating moisture by heated air rests upon the fact that the capacity of air for moisture is rapidly increased by rise in temperature. If air at 52° is heated to 72°, its capacity for moisture is doubled, and is four times what it was at 32°. The following table gives the weight of a saturated mixture of air and aqueous vapor at different temperatures up to 160° — the practical limit of heating air by steam, together with the weight of vapor, in pounds and percentage, and total heat, the portion contained in the vapor and the quantity of air required per pound of water.

By the inspection of this table it will be seen why it is more economical to dry at the higher temperatures. The atmosphere is seldom saturated with moisture, and in practice it will be found generally necessary to heat the air about 30° above the temperature of saturation. The best effect is produced where there is artificial ventilation, by fan or by chimney, and the course of the heated air is from above downwards.

SATURATED MIXTURES OF AIR AND AQUEOUS VAPOR.

Temperature, degrees Fah.	Weight of 100 cubic feet of mixture in lbs.	Weight of water in 100 cubic feet of mixture in lbs.	Per cent. of water in mixture.	Heat units in 100 cubic feet of mixture.	Per cent. of heat in vapor.	Dry air required for vapor in mixture. Lbs.	Cubic feet.
35	8.004	0.034	0.42	42.8	86.69	234.4	3080
40	7.920	0.041	0.52	59.8	76.59	192.2	2526
45	7.834	0.049	0.62	77.7	68.98	158.9	2088
50	7.752	0.059	0.76	97.6	66.29	130.4	1714
55	7.688	0.070	0.91	118.3	64.58	108.5	1326
60	7.589	0.082	1.08	140.1	64.31	91.6	1203
65	7.507	0.097	1.29	164.9	64.76	76.4	1004
70	7.425	0.114	1.49	189.7	66.21	66.0	868
75	7.342	0.134	1.79	221.6	66.74	55.0	723
80	7.262	0.156	2.15	253.6	68.02	45.6	599
85	7.178	0.182	2.54	289.7	69.66	38.4	505
90	7.108	0.212	2.98	330.2	71.19	32.5	427
95	7.009	0.245	3.50	373.4	72.87	27.6	363
100	6.924	0.283	4.08	422.0	74.58	23.5	308
105	6.830	0.325	4.76	474.7	76.22	20.0	263
110	6.741	0.373	5.23	533.9	77.88	17.1	224
115	6.650	0.426	6.41	599.1	79.52	14.6	192
120	6.551	0.488	7.46	672.4	81.14	12.6	163
125	6.454	0.554	8.55	750.5	82.62	10.7	140
130	6.347	0.630	9.90	839.4	84.13	9.1	118
135	6.238	0.714	11.44	936.7	85.57	7.7	102
140	6.131	0.806	13.14	1042.7	86.89	6.6	87
145	6.015	0.909	15.11	1160.6	88.18	5.6	74
150	5.891	1.022	17.33	1288.4	89.39	4.8	63
155	5.764	1.145	19.88	1427.4	90.53	4.0	53
160	5.679	1.333	23.47	1638.7	91.93	3.3	43

Examiner Building, San Francisco, Cal. 530 H.P. Babcock & Wilcox Boilers.

FLOW OF STEAM THROUGH PIPES.

The approximate weight of any fluid which will flow in one minute through any given pipe with a given head or pressure may be found by the following formula: —

$$W = 87 \sqrt{\frac{D\,(p_1 - p_2)\,d^5}{L\left(1 + \frac{3.6}{d}\right)}}$$

in which W = weight in pounds avoirdupois, d = diameter in inches, D = density or weight per cubic foot, p_1=the initial pressure, p_2=pressure at end of pipe, and L = the length in feet.

The following table gives, approximately, the weight of steam per minute which will flow from various initial pressures, with one pound loss of pressure through straight smooth pipes, each having a length of 240 times its own diameter.

TABLE OF FLOW OF STEAM THROUGH PIPES.

Initial Pressure by Gauge. Pounds per Square Inch.	Diameter of Pipe, in inches. Length of each = 240 diameters.													
	¾	1	1½	2	2½	3	4	5	6	8	10	12	15	18
	Weight of Steam per Minute, in pounds, with one pound loss of pressure.													
1	1.16	2.07	5.7	10.27	15.45	25.38	46.85	77.3	115.9	211.4	341.1	502.4	804	1177
10	1.44	2.57	7.1	12.72	19.15	31.45	58.05	95.8	143.6	262.0	422.7	622.5	996	1458
20	1.70	3.02	8.3	14.94	22.49	36.94	68.20	112.6	168.7	307.8	496.5	731.3	1170	1713
30	1.91	3.40	9.4	16.84	25.35	41.63	76.84	126.9	190.1	346.8	559.5	824.1	1318	1930
40	2.10	3.74	10.3	18.51	27.87	45.77	84.49	139.5	209.0	381.3	615.3	906.0	1450	2122
50	2.27	4.04	11.2	20.01	30.13	49.48	91.34	150.8	226.0	412.2	665.0	979.5	1567	2294
60	2.43	4.32	11.9	21.38	32.19	52.87	97.60	161.1	241.5	440.5	710.6	1046.7	1675	2451
70	2.57	4.58	12.6	22.65	34.10	56.00	103.37	170.7	255.8	466.5	752.7	1108.5	1774	2596
80	2.71	4.82	13.3	23.82	35.87	58.91	108.74	179.5	269.0	490.7	791.7	1166.1	1866	2731
90	2.83	5.04	13.9	24.92	37.52	61.62	113.74	187.8	281.4	513.3	828.1	1219.8	1951	2856
100	2.95	5.25	14.5	25.96	39.07	64.18	118.47	195.6	293.1	534.6	862.6	1270.1	2032	2975
120	3.16	5.63	15.5	27.85	41.93	68.87	127.12	209.9	314.5	573.7	925.6	1363.3	2181	3193
150	3.45	6.14	17.0	30.37	45.72	75.09	138.61	228.8	343.0	625.5	1009.2	1486.5	2378	3481

For sizes of pipe below 6-inch, the flow is calculated from the *actual* areas of "standard" pipe of such nominal diameters.

For horse-power, multiply the figures in the table by 2. For any other loss of pressure, multiply by the square root of the given loss. For any other length of pipe, *divide 240 by the given length expressed in diameters, and multiply the figures in the table by the square root of this quotient*, which will give the flow for 1 lb. loss of pressure. Conversely, dividing the given length by 240 will give the loss of pressure for the flow given in the table.

The loss of head due to getting up the velocity, to the friction of the steam entering the pipe, and passing elbows and valves, will reduce the flow given in the tables. The resistance at the opening, and that at a globe valve, are each about the same as that for a length of pipe equal to 114 diameters divided by a number represented by 1 + (3.6 ÷ diameter). For the sizes of pipes given in the table, these corresponding lengths are: —

¾	1	1½	2	2½	3	4	5	6	8	10	12	15	18
20	25	34	41	47	52	60	66	71	79	84	88	92	95

The resistance at an elbow is equal to ⅔ that of a globe valve. These equivalents — for opening, for elbows, and for valves — must be added in each instance to the actual length of pipe. Thus a 4 in. pipe, 120 diameter (40 feet) long, with a globe valve and three elbows, would be equivalent to 120 + 60 + 60 + (3 × 40) = 360 diameters long; and 360 ÷ 240 = 1½. It would therefore have 1½ lbs. loss of pressure at the flow given in the table, or deliver $(1 \div \sqrt{1\frac{1}{2}} = .816)$ 81.6 per cent. of the steam with the same (1 lb.) loss of pressure.

FLOW OF STEAM FROM A GIVEN ORIFICE.

Steam of any pressure flowing through an opening into any other pressure, less than three-fifths of the initial, has practically a constant velocity, 888 feet per second, or a little over ten miles per minute; hence the amount discharged in pounds is proportionate to the weight or density of the steam. To ascertain the pounds, avoirdupois, discharged per minute, *multiply the area of opening in inches, by 370 times the weight per cubic foot of the steam.* (See p. 73.)

Or the quantity discharged per minute may be approximately found by Rankine's formula:

$$W = 6\,a\,p \div 7$$

in which W = weight in pounds, a = area in square inches, and p = absolute pressure. The theoretical flow requires to be multiplied by k = 0.93, for a short pipe, or 0.63 for a thin opening, as in a plate, or a safety valve.

Where the steam flows into a pressure more than ⅔ the pressure in the boiler: —

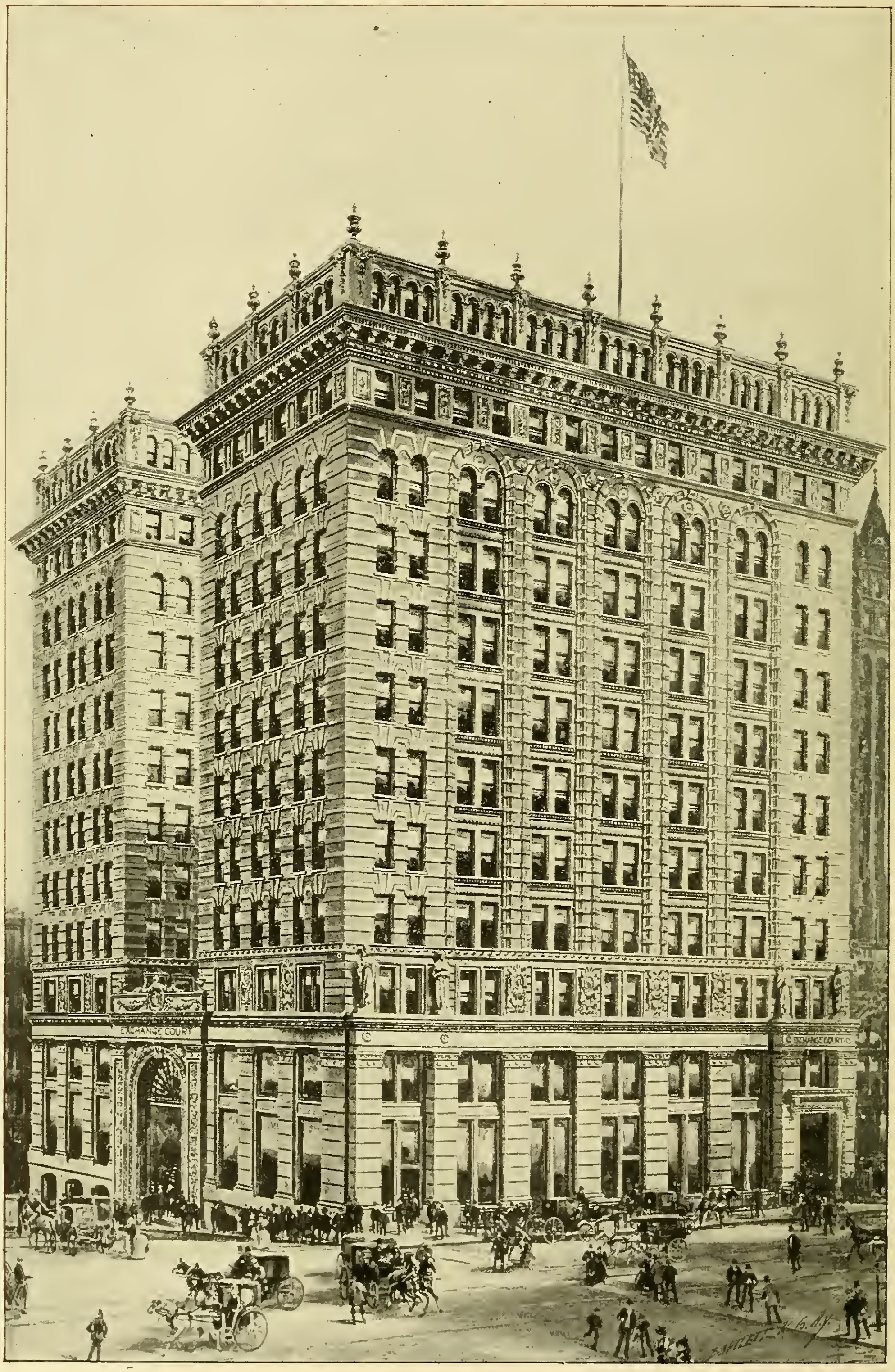
$$W = 1.9\,a\,k\,\sqrt{(p - \delta)\,\delta}$$

in which δ = difference in pressure between the two sides, in pounds per square inch, and a, p, and k as above.

To reduce to horse-power, multiply by 2.

Where a given horse-power is required to flow through a given opening, to determine the necessary difference in pressure: —

$$\delta = \frac{p}{2} - \sqrt{\frac{p^2}{4} - \frac{\text{H.P.}^2}{14a^2\,k}}$$



Exchange Court Building, New York. 632 H.P. Babcock & Wilcox Boilers.

EQUATION OF PIPES.

It is frequently desirable to know what number of one-sized pipes will be equal in capacity to another given pipe for delivery of steam, air, or water. At the same velocity of flow two pipes deliver as the squares of their internal diameters, but the same head will not produce the same velocity in pipes of different sizes or lengths, the difference being usually stated to vary as the square root of the fifth power of the diameter. The friction of a fluid within itself is very slight, and therefore the main resistance to flow is the friction upon the sides of the conduit. This extends to a limited distance, and is, of course, greater in proportion to the contents of a small pipe than of a large. It may be approximated in a given pipe by a constant multiplied by the diameter, or the ratio of flow found by dividing some power of the diameter by the diameter increased by a constant. Careful comparison of a large number of experiments, by different investigators, has developed the following as a close approximation to the relative flow in pipes of different sizes under similar conditions: —

$$W \propto \sqrt{\frac{d^6}{d + 3.6}} \quad \text{or,} \quad \frac{d^3}{\sqrt{d + 3.6}}$$

W being the weight of fluid delivered in a given time, and d being the internal diameter in inches.

The diameters of "standard" steam and gas pipe, however, vary from the nominal diameters, and in applying this rule it is necessary to take the true measurements, which are given in the following table: —

TABLE OF STANDARD SIZES, STEAM AND GAS PIPES.

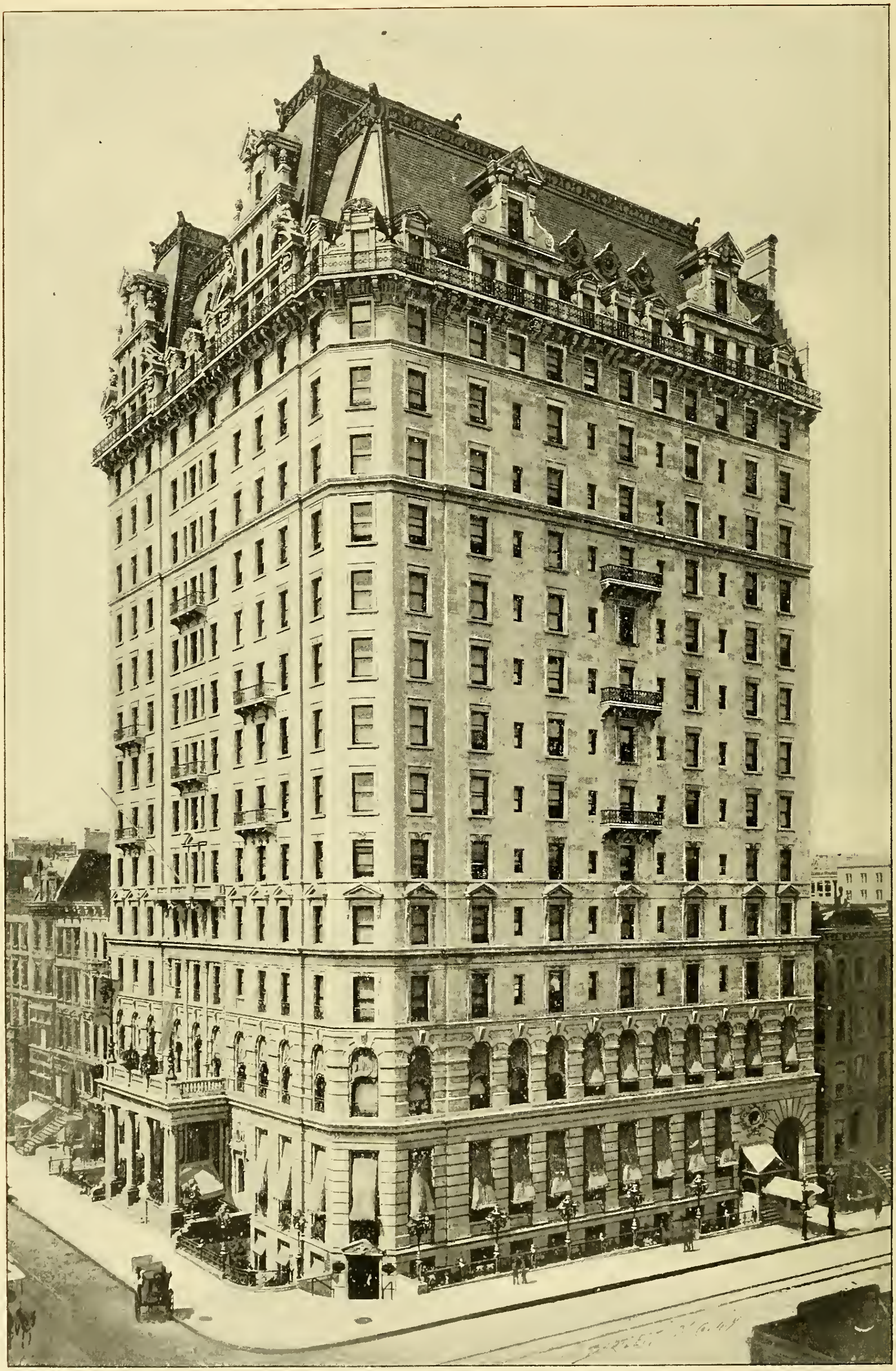
Size, Inches.	Diameter.		Size, Inches.	Diameter.		Size, Inches.	Diameter.	
	Internal.	External.		Internal.	External		Internal.	External.
⅛	.27	.40	2½	2.47	2.87	19	8.94	9.62
¼	.36	.54	3	3.07	3.5	10	10.02	10.75
⅜	.49	.67	3½	3.55	4	11	11.	11.75
½	.62	.84	4	4.03	4.5	12	12.	12.75
¾	.82	1.05	4½	4.51	5	13	13.25	14
1	1.05	1.31	5	5.04	5.56	14	14.25	15
1¼	1.38	1.66	6	6.06	6.62	15	15.43	16
1½	1.61	1.90	7	7.02	7.62	16	16.4	17
2	2.07	2.37	8	7.98	8.62	17	17.32	18

The table below gives the number of pipes of one size required to equal in delivery other larger pipes of same length and under same conditions. The upper portion above the diagonal line of blanks pertains to "standard" steam and gas pipes, while the lower portion is for pipes of the *actual* internal diameters given. The figures given in the table opposite the intersection of any two sizes is the number of the smaller sized pipes required to equal one of the larger. Thus, it requires 29 standard 2 inch pipes to equal one standard 7 inch pipe.

TABLE OF EQUATION OF PIPES.—STANDARD STEAM AND GAS PIPES.

Dia.	½	¾	1	1½	2	2½	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Dia.
½		2.27	4.88	15.8	31.7	52.9	96.9	205	377	620	918	1,292	1,767	2,488	3,014	3,786	4,904	5,927	7,321	8,535	9,717	½
¾	2.60		2.05	6.97	14.0	23.3	42.5	90.4	166	273	405	569	779	1,096	1,328	1,668	2,161	2,615	3,226	3,761	4,282	¾
1	7.55	2.90		3.45	6.82	11.4	20.9	44.1	81.1	133	198	278	380	536	649	815	1,070	1,263	1,576	1,837	2,092	1
1½	24.2	9.30	3.20		1.26	3.34	6.13	13.0	23.8	39.2	58.1	81.7	112	157	190	239	310	375	463	539	614	1½
2	54.8	21.0	7.25	2.26		1.67	3.06	6.47	11.9	19.6	29.0	40.8	55.8	78.5	95.1	119	155	187	231	269	307	2
2½	102	39.4	13.6	4.23	1.87		1.83	3.87	7.12	11.7	17.4	24.4	33.4	47.0	56.9	71.5	92.6	112	138	161	184	2½
3	170	65.4	22.6	7.03	3.11	1.66		2.12	3.89	6.39	9.48	13.3	20.9	23.7	31.2	39.1	50.6	61.1	75.5	88.0	100	3
4	376	144	49.8	15.5	6.87	3.67	2.21		1.84	3.02	4.48	6.30	8.61	12.1	14.7	18.5	23.9	28.9	35.7	41.6	47.4	4
5	686	263	90.9	28.3	12.5	6.70	4.03	1.83		1.65	2.44	3.43	4.69	6.60	8.00	10.0	13.0	15.7	19.4	22.6	25.8	5
6	1,116	429	148	46.0	20.4	10.9	6.56	2.97	1.63		1.48	2.09	2.85	4.02	4.86	6.11	7.91	9.56	11.8	13.8	15.6	6
7	1,707	656	226	70.5	31.2	16.6	10.0	4.54	2.49	1.51		1.41	1.93	2.71	3.28	4.12	5.34	6.45	7.97	9.31	10.6	7
8	2,435	936	322	101	44.5	23.8	14.3	6.48	3.54	2.18	1.43		1.35	1.93	2.33	2.92	3.79	4.57	5.67	6.60	7.52	8
9	3,335	1,281	440	137	60.8	32.5	19.5	8.85	4.85	2.98	1.95	1.37		1.41	1.71	2.14	2.77	3.35	4.14	4.83	5.50	9
10	4,393	1,688	582	181	80.4	42.9	25.8	11.7	6.40	3.93	2.57	1.80	1.32		1.21	1.52	1.97	2.38	2.94	3.43	3.91	10
11	5,642	2,168	747	233	103	55.1	33.1	15.0	8.22	5.05	3.31	2.32	1.70	1.28		1.26	1.63	1.88	2.43	2.83	3.22	11
12	7,087	2,723	938	293	129	69.2	41.6	18.8	10.3	6.34	4.15	2.91	2.13	1.61	1.26		1.30	1.57	1.93	2.26	2.58	12
13	8,657	3,326	1,146	358	158	84.5	50.7	23.0	12.6	7.75	5.07	3.56	2.60	1.98	1.53	1.22		1.21	1.49	1.74	1.98	13
14	10,600	4,070	1,403	438	193	103	62.2	28.2	15.4	9.48	6.21	4.35	3.18	2.41	1.88	1.50	1.22		1.24	1.44	1.64	14
15	12,824	4,927	1,698	530	234	125	75.3	34.1	18.7	11.5	7.52	5.27	3.85	2.92	2.27	1.81	1.48	1.21		1.17	1.35	15
16	14,978	5,758	1,984	619	274	146	88.0	39.9	21.8	13.4	8.78	6.15	4.51	3.41	2.66	2.12	1.73	1.42	1.18		1.14	16
17	17,537	6,738	2,322	724	320	171	103	46.6	25.6	15.7	10.3	7.20	5.27	3.99	3.11	2.47	2.03	1.66	1.37	1.17		
18	20,327	7,810	2,691	840	371	198	119	54.1	29.6	18.2	11.9	8.35	6.11	4.63	3.60	2.87	2.35	1.92	1.59	1.36	1.16	
20	26,676	10,249	3,532	1,102	487	260	157	70.9	38.9	23.9	15.6	10.9	8.02	6.07	4.73	3.76	3.08	2.52	2.08	1.78	1.52	
24	42,624	16,376	5,644	1,761	778	416	250	113	62.1	38.2	25.0	17.5	12.8	9.70	7.55	6.01	4.92	4.02	3.32	2.84	2.43	
30	75,453	28,990	9,990	3,117	1,378	736	443	201	110	67.6	44.2	31.0	22.7	17.2	13.4	10.7	8.72	7.14	5.88	5.03	4.30	
36	120,100	46,143	15,902	4,961	2,193	1,172	705	319	175	108	70.4	49.3	36.1	27.3	21.3	16.9	13.9	11.3	9.37	8.01	6.85	
42	177,724	68,282	23,531	7,341	3,245	1,734	1,044	473	259	159	104	73.0	53.4	40.5	31.5	25.1	20.5	16.8	13.9	11.9	10.1	
48	249,351	95,818	33,020	10,301	4,554	2,434	1,465	663	363	223	146	102	75.0	56.8	44.2	35.2	28.8	23.5	19.4	16.6	14.2	
Dia.	½	¾	1	1½	2	2½	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	

ACTUAL INTERNAL DIAMETERS.



Manhattan Hotel, New York. 1300 H.P. Babcock & Wilcox Boilers.

COVERING FOR BOILERS, STEAM PIPES, ETC.

The loss by radiation from unclothed pipes and vessels containing steam is considerable, and, in the case of pipes leading to steam engines, is magnified by the action of the condensed water in the cylinder. It therefore is important that such pipes should be well protected.

There is a wide difference in the value of different substances for protection from radiation, their value varying nearly in the inverse ratio of their conducting power for heat, up to their ability to transmit as much heat as the surface of the pipe will radiate, after which they become detrimental, rather than useful, as covering. This point is reached nearly at baked clay or brick.

The following table of the relative value of various substances for protection against radiation has been compiled from a variety of sources, mainly the experiments of the Massachusetts Institute of Technology, and of C. E. Emery, M.E., LL.D.

TABLE OF RELATIVE VALUE OF NON-CONDUCTING MATERIALS.

Substance.	Value.	Substance.	Value.	Substance.	Value.
*Loose Wool, ...	3.35	*Paper, ...	.50 to .74	Paste of Fossil Meal and Asbestos, ...	.47
*Loose Lampblack, ...	1.12	*Cork, ...	.71	Asbestos, fibrous, ...	.36
*Geese Feathers, ...	1.08	*Sawdust, ...	.61 to .68	Plaster of Paris, dry, . . .	.34
*Felt, Hair or Wool, ...	1.	Paste of Fossil Meal and Hair, ...	.63	Clay, with vegetable fiber, .	.34
*Carded Cotton, ...	1.	Wood Ashes, ...	.61	Anthracite Coal, powdered, .	.29
*Charcoal from Cork, . . .	.87	*Wood, across grain, . . .	.40 to .55	Coke, in lumps, ...	.27
Mineral Wool, ...	.68 to .83	Loam, dry and open, . . .	.55	Air Space, undivided, . . .	.14 to .22
Fossil Meal, ...	.66 to .79	Chalk, ground, Spanish white,	.51	Sand, ...	.17
*Straw Rope, wound spirally,	.77	Coal Ashes, ...	.35 to .49	Baked Clay, Brick, ...	.07
*Rice Chaff, loose, ...	.76	Gas-house Carbon, ...	.47	Glass, ...	.05
Carbonate Magnesia, . . .	.67 to .76	Asbestos Paper, ...	.47	Stone, ...	.02
*Charcoal from Wood, . . .	.63 to .75				

*Combustible, and sometimes dangerous.

Where two values are given in the table for the same substance the lower one is for the denser condition.

A smooth or polished surface is of itself a good protection, polished tin or Russia iron having a ratio, for radiation, of 53 to 100 for cast iron. Mere color makes but little difference.

Hair or wool felt, and most of the better non-conductors, have the disadvantage of becoming soon charred from the heat of steam at high pressure, and sometimes of taking fire therefrom.

"Mineral wool," a fibrous material made from blast furnace slag, is the best non-combustible covering, but is quite brittle, and liable to fall to powder where much jarring exists.

Air space alone is one of the poorest of non-conductors, though the best owe their efficiency to the numerous minute air cells in their structure. This is best seen in the value of different forms of carbon, from cork charcoal to anthracite dust, the former being three times as valuable for this purpose, though in chemical constitution they are practically identical.

Any suitable substance used to prevent the escape of steam heat should not be less than one inch thick.

The following table gives the loss of heat from steam pipes, naked and clothed with wool or hair felt, of different thickness, the steam pressure being assumed at 75 lbs. and the external air at 60°.

TABLE OF LOSS OF HEAT FROM STEAM PIPES.

Thickness of Covering, in inches.	Outside Diameter of Pipe, without Felt.														
	2 inch diameter.			4 inch diameter.			6 inch diameter.			8 inch diameter.			12 inch diameter.		
	Loss in Units per foot run per hour.	Ratio of Loss.	Feet in Length per H.P. lost.	Loss in Units per foot run per hour.	Ratio of Loss.	Feet in Length per H.P. lost.	Loss in Units per foot run per hour.	Ratio of Loss.	Feet in Length per H.P. lost.	Loss in Units per foot run per hour.	Ratio of Loss.	Feet in Length per H.P. lost.	Loss in Units per foot run per hour.	Ratio of Loss.	Feet in Length per H.P. lost.
0	219.0	1.00	152	390.8	1.00	86	624.1	1.000	53	729.8	1.000	46	1077.4	1.000	31
¼	100.7	.46	331	180.9	.46	182									
½	65.7	.30	507	117.2	.30	284	187.2	.300	177	219.6	.301	151	301.7	.280	114
1	43.8	.20	761	73.9	.18	451	111.0	.178	300	128.3	.176	259	185.3	.172	179
2	28.4	.13	1173	44.7	.11	745	66.2	.106	504	75.2	.103	443	98.0	.091	340
4	19.8	.09	1683	28.1	.07	1186	44.2	.066	808	46.0	.063	724	60.3	.056	553
6				23.4	.06	1424	33.7	.054	989	34.3	.047	972	45.2	.042	735

Bank of Commerce Building and New York Clearing House, containing respectively 566 H.P. and 118 H.P. Babcock & Wilcox Boilers.

CARE OF BOILERS.

The following rules are compiled from those issued by various Boiler Insurance Companies in this country and Europe, supplemented by our own experience. They are applicable to *all boilers*, except as otherwise noted.

ATTENTION NECESSARY TO SECURE SAFETY.

[Though the Babcock & Wilcox boilers are not liable to destructive explosion, the same care should be exercised to avoid possible damage to boiler, and expensive delays.]

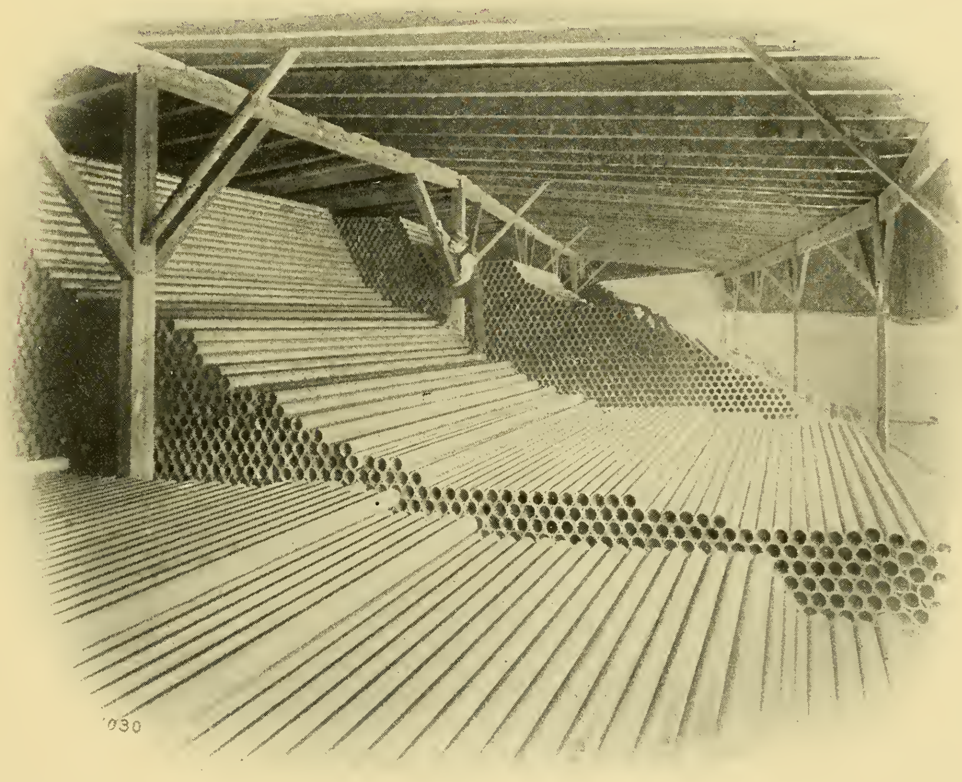
1. Safety Valves.—Great care should be exercised to see that these valves are ample in size and in working order. *Overloading* or *neglect* frequently leads to the most disastrous results. Safety valves should be tried at least once every day to see that they will act freely.

2. Pressure Gauge.—The steam gauge should stand at zero when the pressure is off, and it should show the same pressure as the safety valve when that is blowing off. If not, then one is wrong, and the gauge should be tested by one known to be correct.

3. Water Level.—The first duty of an engineer before starting, or at the beginning of his watch, is to see that the water is at the proper height. Do not rely on glass gauges, floats or water alarms, but try the gauge cocks. If they do not agree with water gauge, learn the cause and correct it. Water level in Babcock & Wilcox boilers should be at center of drum, which is usually at middle gauge. It should not be carried above.

4. Gauge Cocks and Water Gauges must be kept clean. Water gauge should be blown out frequently, and the glasses and passages to gauge kept clean. The Manchester, Eng., Boiler Association attribute more accidents to inattention to water gauges than to all other causes put together.

5. Feed Pump or Injector.—These should be kept in perfect order, and be of ample size. No make of pump can be expected to be continuously reliable without regular and careful attention. It is always safe to have two means of feeding a boiler. Check valves and self-acting feed valves should be frequently



Tube Shed.

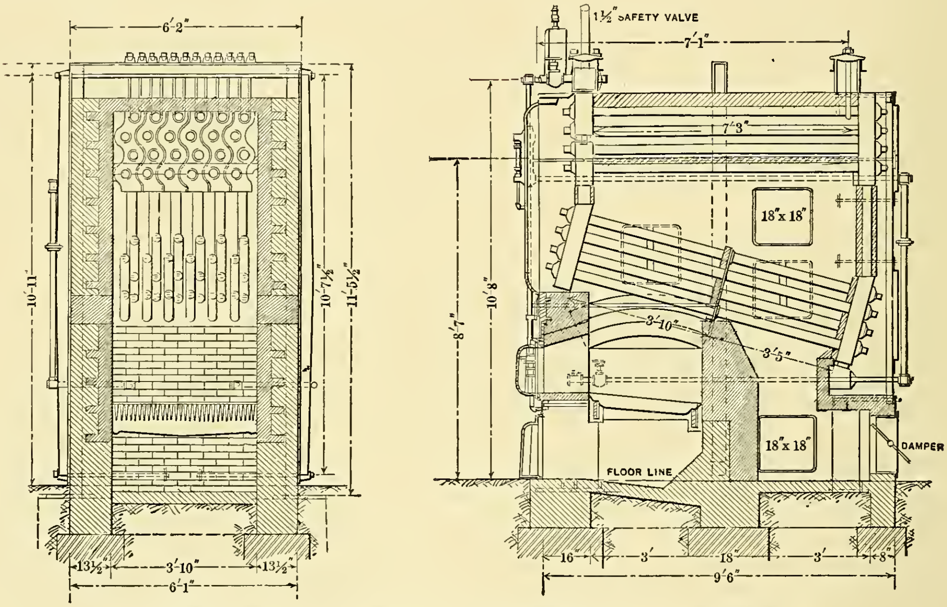
examined and cleaned. Satisfy yourself frequently that the valve is acting when the feed pump is at work.

6. Low Water.—In case of low water, immediately cover the fire with ashes (wet if possible) or any earth that may be at hand. If nothing else is handy use fresh coal. Draw fire as soon as it can be done without increasing the heat. Neither turn on the feed, start or stop engine, nor lift safety valve until fires are out, and the boiler cooled down.

7. Blisters and Cracks.—These are liable to occur in the best plate iron. When the first indication appears there must be no delay in having it carefully examined and properly cared for.

serious waste of fuel. The frequency of cleaning will depend on the nature of fuel and water. As a rule, never allow over $\frac{1}{16}$ inch scale or soot to collect on surfaces between cleanings. Hand-holes should be frequently removed and surfaces examined, particularly in case of a new boiler, until proper intervals have been established by experience.

The Babcock & Wilcox boiler is provided with extra facilities for cleaning, and with a little care can be kept up to its maximum efficiency, where tubulars or locomotive boilers would be quickly destroyed. For inspection, remove the hand-holes at both ends of the tubes, and by holding a lamp at one end and looking in at the other,



25 H.P. Boiler built to carry 300 to 400 lbs. pressure for Nikola Tesla, New York.

8. Fusible Plugs, when used, must be examined when the boiler is cleaned, and carefully scraped clean on both the water and fire sides, or they are liable not to act.

ATTENTION NECESSARY TO SECURE ECONOMY.

9. Firing.—Fire evenly and regularly, a little at a time. Moderately thick fires are most economical, but thin firing must be used where the draught is poor. Take care to keep grates evenly covered, and allow no air-holes in the fire. Do not "clean" fires oftener than necessary. With bituminous coal, a "coking fire," *i. e.*, firing in front and shoving back when coked, gives best results, if properly managed.

10. Cleaning.—All heating surfaces must be kept clean outside and in, or there will be a

the condition of the surface can be fully seen. Push the scraper through the tube to remove sediment, or if the scale is hard use the chipping scraper made for that purpose. Water through a hose will facilitate the operation. In replacing hand-hole caps, clean the surfaces without scratching or bruising, smear with oil, and screw up tight. Examine mud-drum and remove the sediment therefrom.

The *exterior* of tubes can be kept clean by the use of blowing pipe and hose through openings provided for that purpose. In using smoky fuel, it is best to occasionally brush the surfaces when steam is off.

11. Hot Feed-Water.—Cold water should never be fed into any boiler when it can be avoided, but when necessary it should be caused to mix with the heated water before coming in contact with any portion of the boiler.

12. Foaming.—When foaming occurs in a boiler, checking the outflow of steam will usually stop it. If caused by dirty water, blowing down and pumping up will generally cure it. In cases of violent foaming, check the draft and fires.

Babcock & Wilcox boilers never foam with good water, unless the water is carried too high. If found to prime, lower the water line. It should not be carried above center line of drum.

13. Air Leaks.—Be sure that all openings for admission of air to boiler or flues, except through the fire, are carefully stopped. This is frequently an unsuspected cause of serious waste.

14. Blowing Off.—If feed-water is muddy or salt, blow off a portion frequently, according to condition of water. Empty the boiler every week or two, and fill up afresh. When surface blow-cocks are used, they should be often opened for a few minutes at a time. Make sure no water is escaping from the blow-off cock when it is supposed to be closed. Blow-off cocks and check-valves should be examined every time the boiler is cleaned.

Attention Necessary to Secure Durability.

15. Leaks.—When leaks are discovered, they should be repaired as soon as possible.

16. Blowing Off.—Never empty the boiler while the brickwork is hot.

17. Filling Up.—Never pump cold water into a hot boiler. Many times leaks, and, in shell boilers, serious weaknesses, and sometimes explosions are the result of such an action.

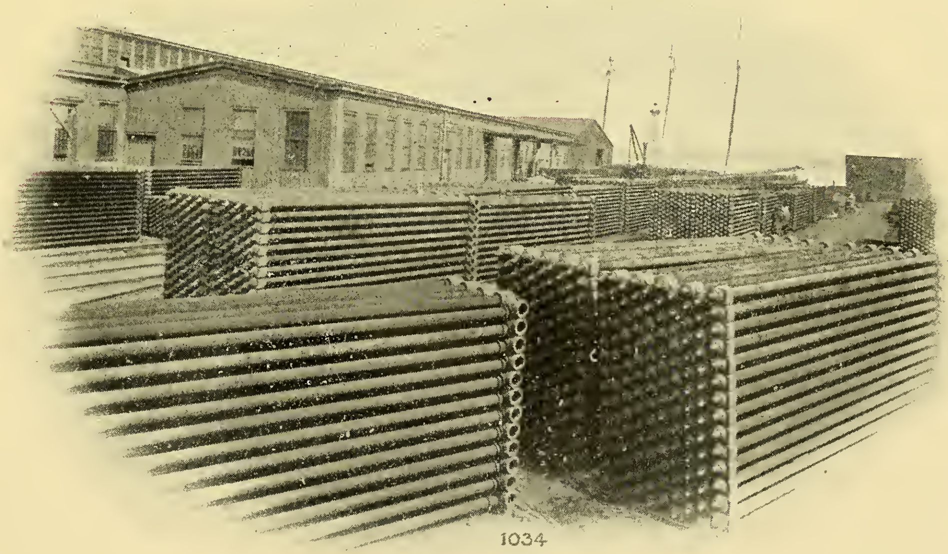
18. Dampness.—Take care that no water comes in contact with the exterior of the boiler from any cause, as it tends to corrode and weaken the boiler. Beware of all dampness in seatings or coverings.

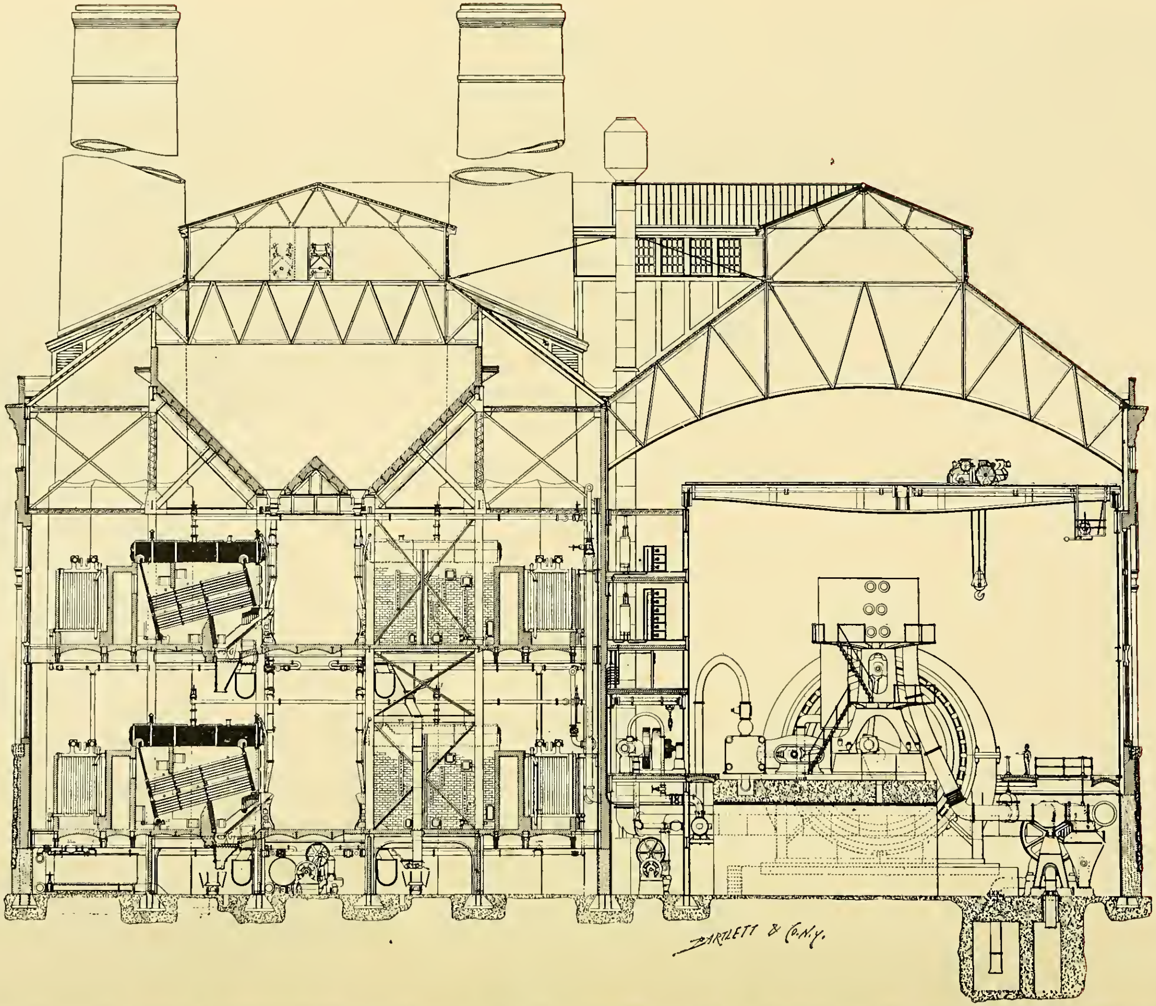
19. Galvanic Action.—Examine frequently parts in contact with copper or brass, where water is present, for signs of corrosion. If water is salt or acid, some metallic zinc placed in the boiler will usually prevent corrosion, but it will need attention and renewal from time to time.

20. Rapid Firing.—In boilers with thick plates or seams exposed to the fire, steam should be raised slowly, and rapid or intense firing avoided. With thin water tubes, however, and adequate water circulation, no damage can come from that cause.

21. Standing Unused.—If a boiler is not required for some time, empty and dry it thoroughly. If this is impracticable, fill it quite full of water, and put in a quantity of common washing soda. External parts exposed to dampness should receive a coating of linseed oil.

22. General Cleanliness.—All things about the boiler room should be kept clean and in good order. Negligence tends to waste and decay.





Cross-Section of Power Station of Manhattan Elevated Railway Co., New York, containing 33,280 H. P. Babcock & Wilcox Boilers fitted with Roney Stokers.

TESTS of the BABCOCK & WILCOX BOILERS

TESTING STEAM BOILERS.

The object of testing a steam boiler is to determine the quantity and quality of steam it will supply continuously and regularly, under specified conditions; the amount of fuel required to produce that amount of steam, and sometimes sundry other facts and values. In order to ascertain these things by observation it is necessary to exercise great care and skill, and employ the most perfect apparatus, or errors will creep in sufficient to vitiate the test and render it of no value, if not actually misleading. This is most apparent in testing the quality of the steam by a "barrel calorimeter" as at the Centennial Exposition, where an error of ¼ pound in either of two weighings of a mass of some 400 pounds made a difference of 3% in the final result.

The principal points to be ascertained and noted in a boiler test are:—

1. The type and dimensions of the boiler, including the area of heating surface, steam and water space, area of water surface, and draft area through or between tubes or flues.

2. The kind and size of furnace; area of grate with proportion of air spaces therein, height and size of chimney, length and area of flues or tubes.

3. Kind and quality of fuel, if coal from what mine, etc.; percentage of refuse, and percentage of moisture. The latter is a more important item than is generally understood, as in adding directly to the weight it introduces an error in the final results directly proportioned to the per cent. of the fuel.

4. Temperature of feed-water entering boiler and temperature of flue gases. The temperatures of fire-room and of external air may be noted, but are usually of slight importance.

5. Pressure of steam in boiler, draft pressure in furnace at boiler side of damper in flue connection with breeching or stack, and the blast, if any, in the ash pit.

6. Weights of feed-water, of fuel, and of ashes. Water meters are not reliable as an accurate measure of feed-water.

7. Time of starting and of stopping test, taking care that the observed conditions are the same at each, as far as possible.

8. The quality of the steam, whether "wet," "dry," or superheated.

From these data all the results can be figured, giving the economy and capacity of the boiler and the sufficiency or insufficiency of the conditions, for obtaining the best results.

For purposes of comparison with other tests, the water actually evaporated under the observed conditions per pound of coal and combustible and per square foot of heating surface per hour are reduced to what is called "Equivalent Evaporation" from and at 212°. In other words, the results are reduced to certain standard conditions for all tests, namely: Pressure equal to that of the atmosphere, and the temperature of the feed-water 212°.

These equivalent results are ascertained by multiplying the actual results by a so-called "factor of evaporation" which is found by means of the formula:—

$$\text{Factor of evaporation} = \frac{H-h}{965.8}$$

in which H = total heat above 32° in steam at boiler pressure; h = total heat above 32° in 1 pound of feed-water (see table, page 73); 965.8 = latent heat of steam at atmospheric pressure.

The standard boiler horse-power, 30 pounds water evaporated per hour from a temperature of 100° to steam at 70 pounds pressure, is equal to about 34½ pounds from and at 212°.

For further information concerning the making of boiler tests, see Transactions of the American Society of Mechanical Engineers, Vol. VI., pages 256–357.

ENGINEERING OFFICE OF CHAS. E. EMERY,
No. 7 WARREN STREET, NEW YORK,
March 21, 1879.

MESSRS. BABCOCK & WILCOX,
No. 30 Cortlandt Street, New York.

GENTLEMEN: On the 4th and 5th of February, 1879, I made a trial of the Babcock & Wilcox Boilers and Corliss engines in the Raritan Woolen Mills, Raritan, N. J., the results of which are shown in the following report:—

New York Life Building, 225 H.P. Babcock & Wilcox Boilers. Montreal, Canada. Notre Dame Cathedral, 122 H.P. Babcock & Wilcox Boilers.

There were two boilers tested of the water-tube type, manufactured by you and known by your name, rated jointly at 360 horse-power, and reported to contain 4,080 square feet of heating surface, and 103 square feet of grate surface. These boilers were erected side by side and connected so that they could be used separately or conjointly in connection with or independent of a number of Lancashire drop-flue boilers, three boilers of the latter kind having been removed to make room for yours. All the boilers were connected to a single chimney through a Green's economizer in the flue. A large portion of the steam generated appeared to be used in the dye house and for heating purposes. A portion of the boilers were employed, however, to supply steam to two pairs of engines, of equal size, operating the mill, one pair being of the Wright patent, put in many years since, and the other of Corliss make, erected within a year. Each steam cylinder was 20 inches in diameter with 48 inches stroke of piston. The engines are provided with Bulkley condensers. In the ordinary working of the mill your boilers were used to supply steam to both pairs of engines.

Your contract contained a guarantee that the boilers should furnish sufficient steam to develop the rated power (360 H. P.) in a Corliss engine, and that the evaporation should equal at least 9 pounds of water from a temperature of 180° per pound of coal containing not more than 12 per cent. of refuse. In a preliminary trial part of the load on the Wright engines was transferred to the Corliss engines; but it was soon found that the latter did not require all the steam your boilers would generate economically; so two trials were made, one of $4\frac{1}{6}$ hours' duration, using your boilers with reduced draft to supply steam to the Corliss engines only, and taking data to ascertain the economy of the engines; the other of fully 12 hours' duration, using the boilers at *maximum power* on a dull day without forcing the fires, part of the steam being used to operate the Corliss engines, the remainder blown into the pipe system of the other boilers, which were working at a much less pressure.

Trial of the Boilers.

The experiment commenced at 6.01 A.M., and closed at 6.38 P.M. In starting, steam was raised by spreading the banked fires left from the previous day. When the pressure reached 80 pounds the fires were hauled, all refuse removed, and fires started anew with wood, which in calculation has been considered equal in calorific value to $\frac{4}{10}$ its weight of coal. The fires were maintained with coal during the day, finally hauled, allowed to cool, the combustible portion deducted from the coal charged, and the refuse weighed separately. The experiment was closed when the boilers stopped making steam at 80 lbs. pressure, with water in the glass gauges at same height as in starting.

During the trial, all the coal consumed was weighed in an iron wheelbarrow, balanced when empty by a fixed weight, and each barrow load was adjusted at the scale to weigh 200 pounds net. All the water evaporated was measured in a tank provided with a heavy float connected through a fine chain to an index showing a water level on an exterior scale, divided decimally. By weighing water out of the tank, its capacity was found to be 5,172 pounds of water between the limits employed.

A complete record was kept of the coal, water, steam pressure and various temperatures, and the quality of the steam was tested with a calorimeter at frequent intervals. The proprietors of the mill took the proper business precaution of stationing observers at each point, who kept entirely independent records, agreeing with those taken by my assistants. The coal used was clean nut coal from the Lackawanna region. It had been exposed to the weather during the winter, and when first taken from the pile was wet, but a sufficient quantity for the trial was brought under shelter a few days in advance, so that the coal actually used was bright and appeared dry. The results of the trial are as follows:—

Average steam pressure, ...			71.63
Average temperature of fire room, ...			44.00
Average temperature of water in feed tank, ...			90.47
Average temperature of water entering boiler after passing through a heater in flue, ...			110.59
Average temperature of up-take boiler No. 1 by pyrometer (evidently wrong), ...			381.87
Average temperature of flue beyond feed-water heater,			453.23
Wood used in starting fires, 730 lbs., equivalent of coal (730 X.4), ...	lbs.,	292	
Coal put in furnaces during experiment, . .	lbs.,	19,827	
Total of above, ...	lbs.,		20,119
Combustible in refuse at close of experiment,	lbs.,		820
Total coal consumed, including equivalent of wood, ...	lbs.,		19,299
Refuse from coal removed during experiment,	lbs.,	749	
Refuse from coal at close of experiment, .	lbs.,	2,134	
Total, ...	lbs.,		2,883
Actual percentage of refuse, (2,883 ÷ 19,299 X 100 =)			14.94
Combustible consumed, (19,299 — 2,883 =) . .	lbs.,		16,416
Coal with 12 per cent. refuse agreed upon, equivalent to that actually consumed, [16,416÷(100—12)=]	lbs.,		18,654.5
Total weight of water actually evaporated at pressure of 71.63 lbs. from temperature 110.59°,	lbs.,		161,573.28
Equivalent evaporation at pressure of 70 lbs. from temperature of 180°, as agreed upon, . .	lbs.,		172,592.58
Evaporation per lb. of coal, with 12 per cent. of refuse, at pressure of 70 lbs. from temperature of 180°,			**9,252**
Evaporation per lb. of combustible, atmospheric pressure, from temperature of 212°, ...			**11,221**

New York and Brooklyn Suspension Bridge, using 1,786 H.P. Babcock & Wilcox Boilers.

Calorimeter Trials.

The calorimeter consisted of a simple barrel set on a platform scale. The scale beam was graduated for half-pounds only; but by applying thereto an extra movable weight, one-tenth that of the other, carefully leveling the platform, and in weighing bringing the end of the beam just clear of the guard, it was possible to read to one-tenth, or even .05 of a pound. In an inclined position, through the side of the barrel, was fixed a thermometer graduated to ¼ degrees, and readily read to ⅛ degrees. A small iron propeller on a vertical shaft was arranged in the barrel. In operations the barrel was nearly filled with cold water, which was heated with steam, when the increase in weight showed the weight of steam taken from the boiler, and the increase in temperature measured the quantity of heat in the steam. The steam was taken from the boiler near the issuing current, through a 2 inch pipe reduced outside of the boiler to ¾ of an inch, and again near the outer end by an inserted nipple to $\frac{5}{16}$ of an inch, substantially on the plan recommended in a previous article on the subject.* To the end of the steam pipe a short piece of hose was connected through a valve; the pipe was carefully felted, and was heated previous to each experiment by wasting steam through it before putting the hose into the calorimeter. The end of the hose was perforated in several directions, to avoid the jar due to condensation.

Seventeen experiments were made during the day; one was rejected, in which the thermometer scale was seen to move by bringing the hose too near the instrument. The results were calculated from the records of the remaining sixteen experiments, on the following basis: —

Let W = original weight of water in calorimeter.
Let w = weight of water added by heating with steam.
Let T = total heat in water due to the temperature of steam at observed pressure.
Let H = total heat of steam at observed pressure.
Let l = latent heat of steam at observed pressure.
Let t = total heat of water corresponding to temperature of water in calorimeter.
Let t' = total heat in water corresponding to final temperature of water in calorimeter.
Let E = heating efficiency of the steam furnished, compared with saturated steam between the same limits of temperature.
Let Q = quality of steam explained hereafter.

$$\text{Then } E = \frac{W\,(t'-t)}{w\,(H-t')} \quad \ldots\ldots\ldots (1)$$

The value of E was ascertained by the formula separately for each experiment. The average value was .9916, showing that the steam lacked but $\frac{84}{100}$ of 1 per cent. of the quantity of heat required for producing perfectly dry or saturated steam between the same limits of temperature.

The value of Q may be found directly from the following equation: —

$$Q = \frac{1}{l}\left(\frac{W}{w}(t'-t) - (T-t')\right) \ldots . (2)$$

or, from the average of the heating efficiencies, by the following: —

$$Q = 1 - \frac{(H-t')\ (1-E)}{l} \ldots\ldots\ldots (3)$$

Then when $Q < 1$, the percentage of moisture in steam $= 100\,(1-Q)$.

When $Q > 1$, the number of degrees steam is superheated $= 2.0833\, l\,(Q-1)$.

In the present case $Q = .98955$. Percentage of moisture in steam = 1.045.

This is *practically dry steam*, and equal in quality to that furnished by boilers of any type not provided with superheating surface. The experiments show, in a gratifying manner, that you have succeeded in overcoming a great difficulty often experienced with boilers constructed of a combination of small chambers to reduce the danger of explosion. The deficiency of ordinary boilers in furnishing dry steam is little known, though the economy is materially affected.

Engine Trials.

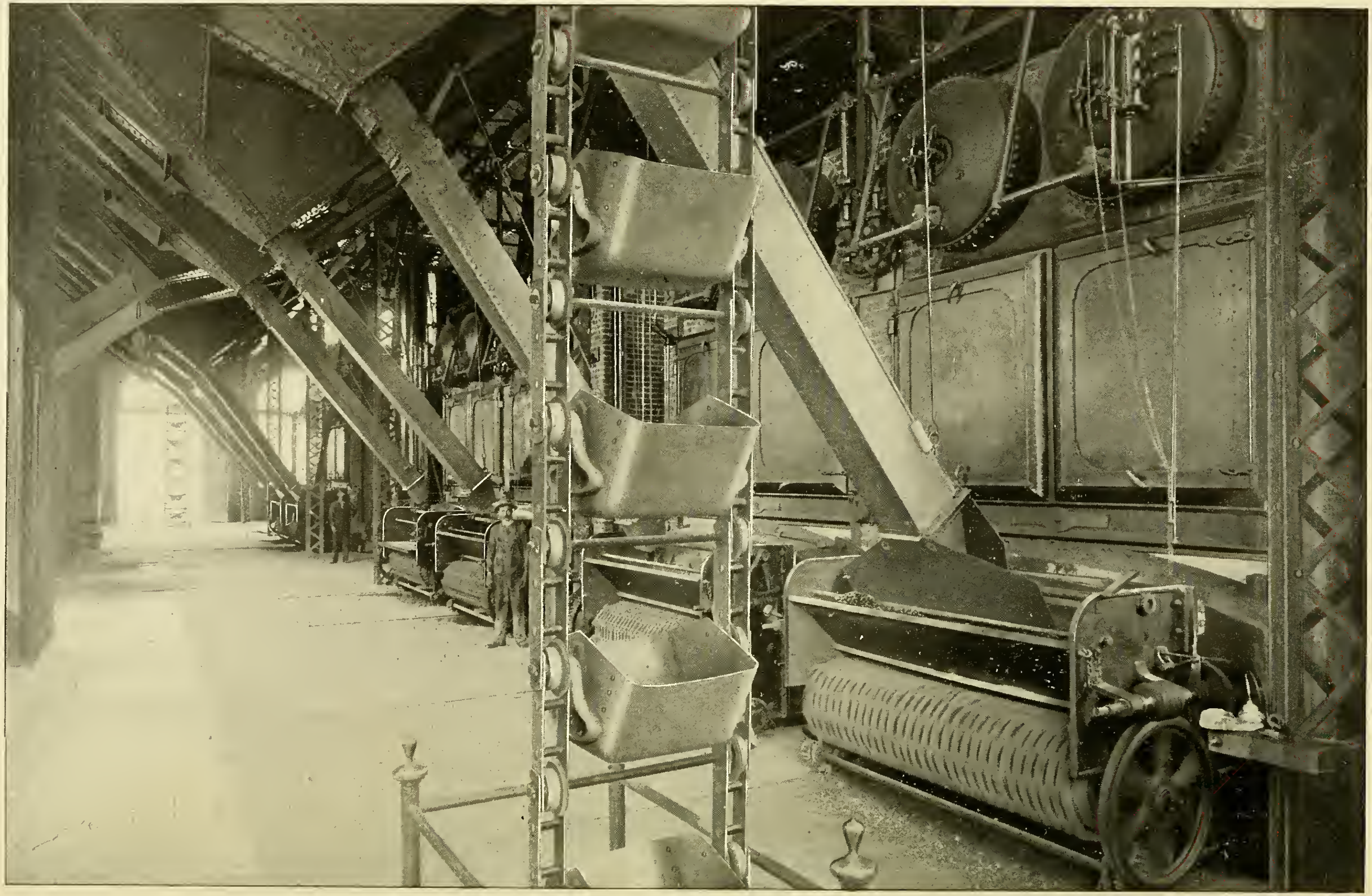
The preliminary trial of engines gave the following results: —

Duration of experiment, ...	4.1	hours.
Average steam pressure in boilers, ...	93.94	pounds.
Average vacuum in condenser, ...	21.5	inches.
Average revolution of engine per minute, .	64.492	
Water evaporated per hour, ...	8830.244	pounds.
Average initial pressure in steam cylinders, .	84.425	pounds.
Mean effective pressure in cylinders, . . .	30.1275	pounds.
Average point of cut-off, ...	.129	stroke.
Average indicated H.P. (both engines), . .	292.613	
Maximum H.P. shown by a complete set of diagrams, ...	315.580	
Water per indicated horse-power per hour, .	30.177	pounds.

The steam pipe was 131 feet long, and other conditions were unfavorable for the economical development of power in the engines. It is, in fact, popularly supposed that this class of engines develops a horse-power for ⅔ the quantity of steam required in this case.

The duration of the boiler experiment was 12 hours and 37 minutes, of which fully 13 minutes were necessarily lost in starting and hauling fires. On this basis the water was evaporated in 12.4 hours, or at the equivalent rate of 13,919 pounds per hour for feed-water at 180 degrees. On the basis that any good engine under fair conditions will require but 30 pounds of water per horse-power per hour your boilers, during this experiment, though not forced to their utmost, devel-

* Report of Judges, Group XX, Centennial Exhibition, p. 82.



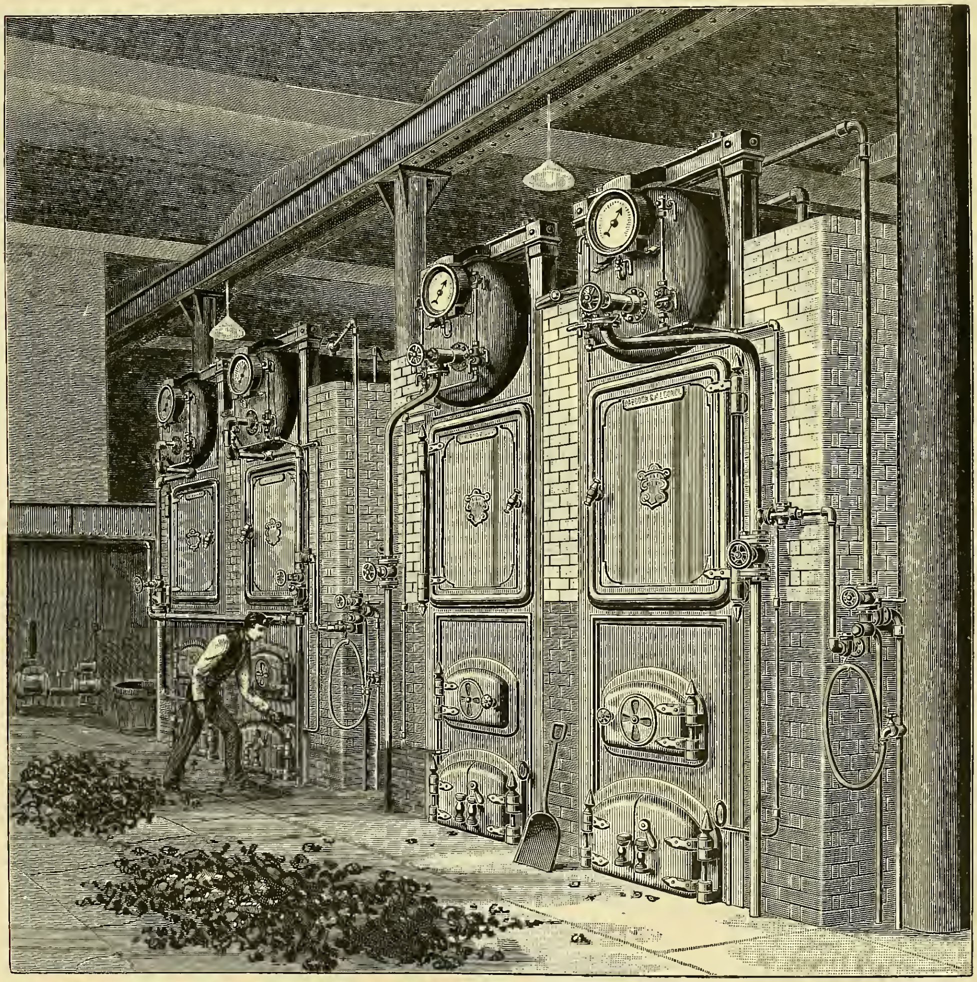
Metropolitan Street Railway Company, Kansas City, Mo.   13,120 H.P. Babcock & Wilcox Boilers, and Chain Grate Stokers.

oped under condition agreed upon, 13,919 ÷ 30 = 464 horse-power, *or 104 horse-power in excess of the guaranteed power.*

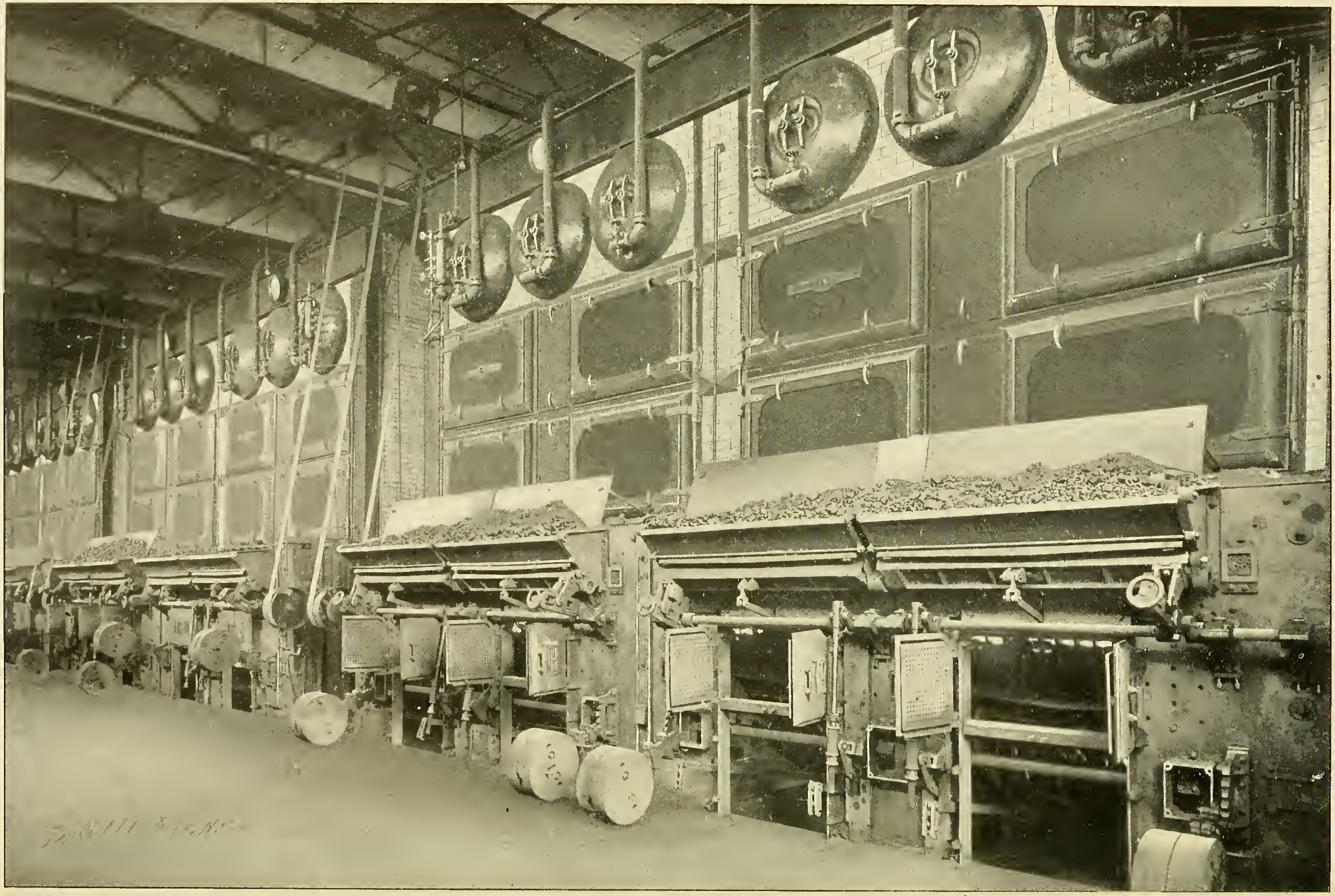
The coal required per horse-power per hour is evidently dependent in any case upon the economy of the boiler and engine jointly. With an evaporation of 9.252 pounds of water per pound of coal, and 30 pounds of water per horse-power in the engine, there would be required per horse-power per hour 3.24 pounds of coal. This boiler performance, however, is rarely obtained in ordinary practice, so generally a low cost of power in fuel is due to using an excellent engine with a fair boiler. For instance, during the official trial of one of the most prominent pumping engines in this country, the boilers, which were specially designed to secure economy, actually evaporated but 8.31 pounds of water at a pressure of 89.4 pounds from a temperature 100° per lb. of *Cumberland* coal; yet the engine was so economical that there was required but 1.69 lbs. of coal per horse-power per hour. The equivalent evaporation of your boilers from the same temperature with *anthracite nut* coal, much inferior to Cumberland, on the basis of the trial above mentioned, is 8.547 pounds of water per pound of coal; so if your boilers were used in connection with that particular pumping engine, there would be required but 1.64 pounds of the inferior coal per horse-power per hour.

The economical performance of your boilers could undoubtedly be rendered still greater by reducing the rate of evaporation. To accomplish this result to the fullest extent, however, the boiler would probably need to be so proportioned that it would not develop a maximum of 464 horse-power, or upward, as in its present form.

Very truly yours, CHAS. E. EMERY.



Babcock & Wilcox Boilers at the Chelsea Electricity Supply Company's Station, Chelsea, Eng. 360 H.P. Erected 1888-9. The Brush Electric Engineering Co., Limited, London, Contractors.

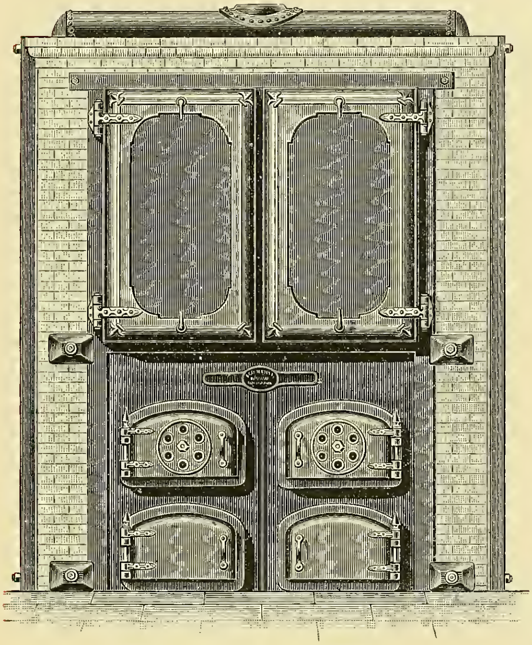


Harvard Square Station, Boston Elevated Railway Co. Babcock & Wilcox Boilers fitted with Acme Stokers. 24,500 H. P. Babcock & Wilcox Boilers used in their various stations.

THE UNPARALLELED RECORD

Of the Babcock & Wilcox Water-Tube Boilers, as shown in the preceding pages, proves once again, and particularly in regard to boilers, what has been frequently proved in regard to other things, that "the best is the cheapest," no matter what may be the first cost.

In purchasing boilers the buyer wishes to be assured on six points, two regarding the parties with whom he is dealing, and four pertaining to the article to be purchased. Of the former he wishes to know, first, if the party is financially responsible and has such reputation that he may depend upon being honorably treated, and, second, if the manufacturer is likely to remain long enough in business to supply needed repairs from the special patterns employed.



Front of a Cross Drum Boiler.

In regard to the boiler he needs to know: —

1. — Its Reliability: Whether it can be depended upon to do his work through thick and thin. *Long and satisfactory use* by different persons under various conditions is the best answer to this question.

2. — Its Economy: Whether it will be wasteful or saving in the use of fuel. Economy is claimed in behalf of every boiler made, and many times to an extravagant and impossible extent. Here again *a long and favorable record is the only certain criterion.*

3. — Its Safety: Whether it is liable to explode and cause a greater damage to life and property than it, with all its other advantages, is worth. Time is also necessary to prove the truth of claims in this respect.

4. — Its Durability: Will it require early or extensive repairs, or have soon to be replaced with another construction? *Nothing but a long-continued use can determine this point.* No less than thirty competitors in water-tube boilers have arisen, flourished for a short time, and then sunk to oblivion since the Babcock & Wilcox boiler was first introduced. Of nine sectional boilers at the U. S. Centennial, the Babcock & Wilcox is the only one now manufactured, thus justifying the caution of the judges, who, in awarding the prizes, said that time alone could determine the value of the construction. He who buys an untried invention takes all the risk of its success.

It is Reliable.

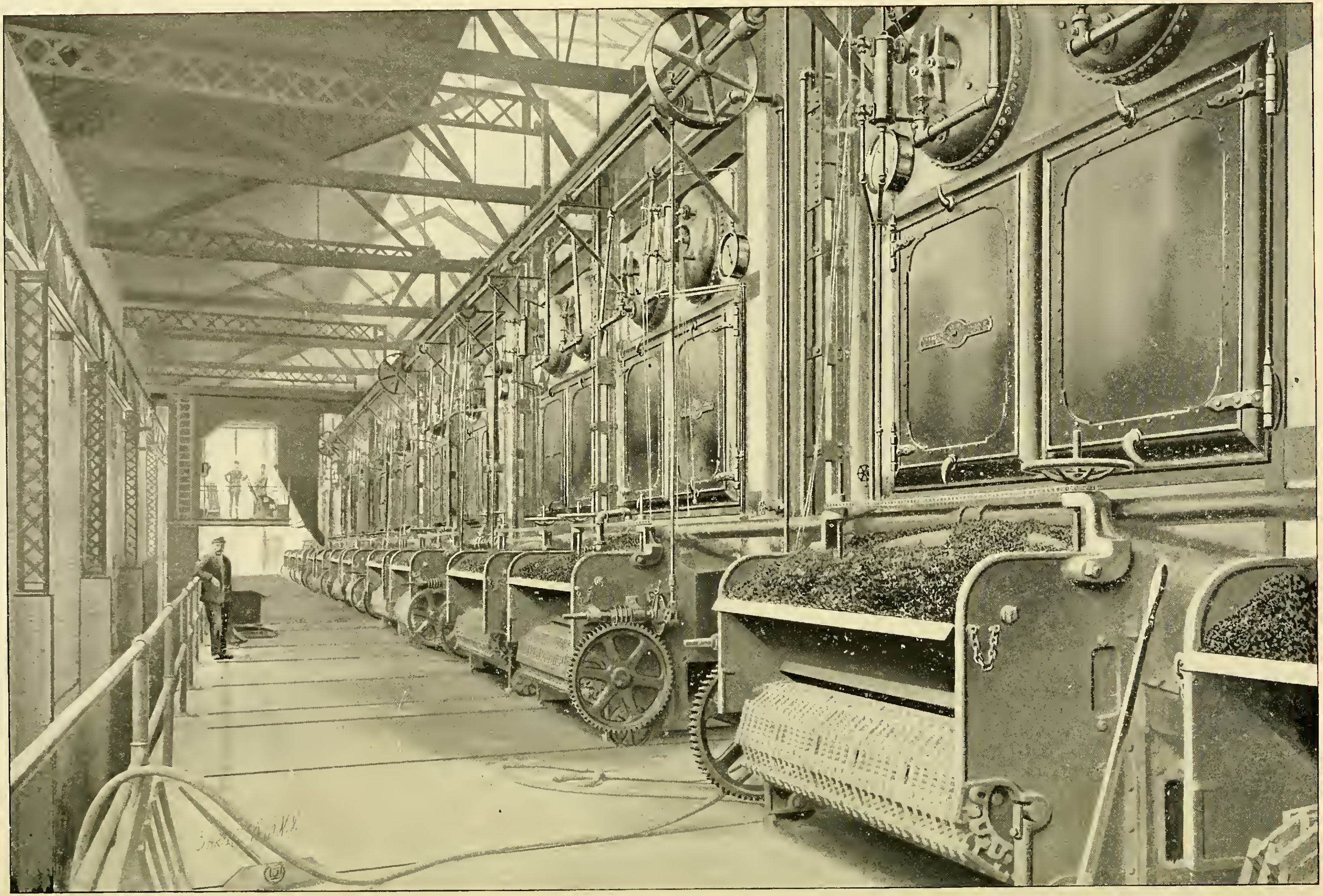
The long list of purchasers, extending over thirty years, the continued and repeated orders from those who know it best, with the fact that it has made its way against all opposition into extended use in all parts of the known world, and into the most exacting trades, demanding the establishment of manufactories in four countries, is sufficient proof on this point.

It is Economical.

The table given of thirty tests, extending from Glasgow to San Francisco, with many kinds of coal, and under many conditions, in which an aggregate of *over thirty-one hundred tons of water* were evaporated, with a little over two hundred and seventy tons of combustible, shows an actual economy within about seven per cent. of the highest theoretically practical under similar conditions. It is quite safe to say that no other boiler can show a better record for economy.

It is Safe.

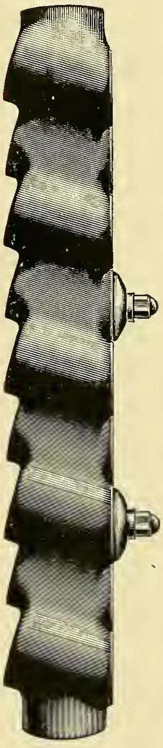
On this point the record is complete. Boilers developing NEARLY TWO MILLION HORSE-POWER, sold during thirty years without loss of life or property by explosion, is a record without parallel. Other so-called "Safety" boilers have exploded, but the Babcock & Wilcox never, though, probably, more of them have been put into use than of all others combined. There are boilers now offered in the market as "Safety" boilers which have no other claim to the distinction than the deceptive name.



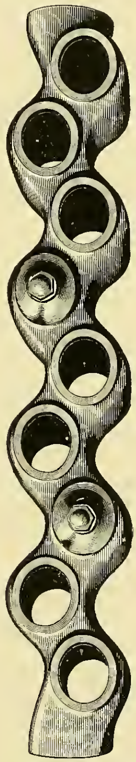
Babcock & Wilcox Boilers, fitted with Babcock & Wilcox Chain Grate Stokers, in Ford City Plant of Pittsburgh Plate Glass Co. 16,842 H.P. in various plants of this Company.

It is Durable.

The wonderful record *of over one hundred thousand horse-power of these boilers in use from two to twenty years, many of them driven day and night, on which the average cost of repairs has not exceeded FIVE CENTS YEARLY PER HORSE-POWER for the boiler proper from all causes*, speaks volumes on this point. What does it mean? It means that the wear and tear, including accidents, on the average is about *one-half of one per cent. per annum upon the cost* (not including furnaces and masonry), while that of a tubular boiler is rarely estimated at less than *ten per cent.* As to the lifetime of a Babcock & Wilcox boiler,



Side View of Vertical Header.



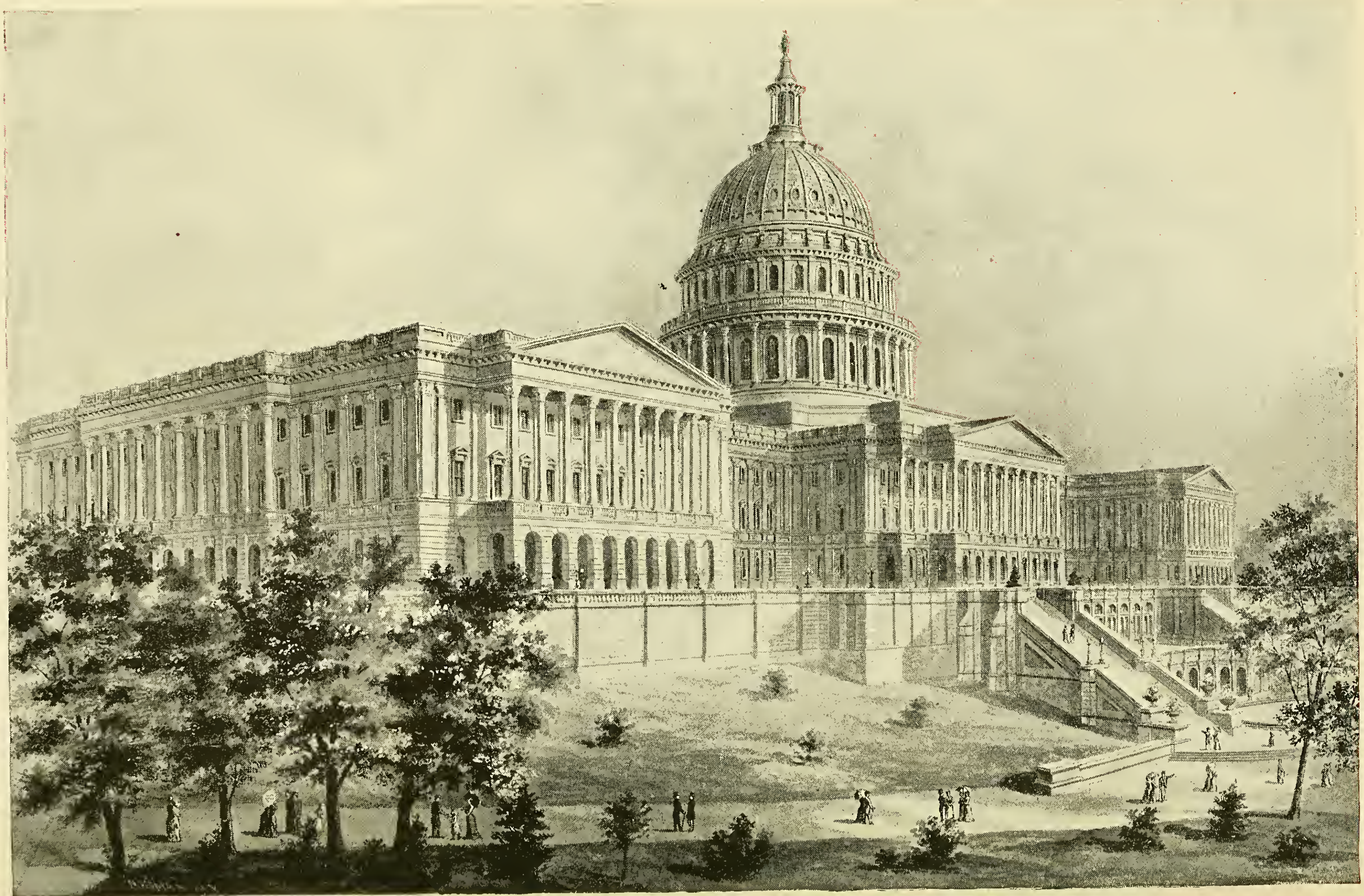
Front View of Vertical Header.

experience so far fixes no data for a limit. Thirty years' use has developed no single instance of a boiler being worn out in legitimate service, and when worn or damaged small repair has apparently restored them to their pristine youth. We see no reason to suppose that at the end of fifty years, with the occasional replacing of damaged parts, they may not be "as good as new."

For many years we published in this book a list of the users of the Babcock & Wilcox boilers but the list has become so large that we are forced to omit it. To anyone desiring references we shall be glad to furnish as many as desired.

The following summary will give something of an idea of extensive use of Babcock & Wilcox boilers in different industries: —

	Horse-Power.
Agricultural Machinery,	8,776
Bolts, Screws, and Nails,	5,669
Bricks and Cement,	10,456
Cable Railways,	27,104
Carpets and Oilcloth,	7,258
Cars, Wagons, and Bicycles,	7,290
Chemicals, Glue, and Fertilizer,	39,494
Clothing and Furnishing Goods,	3,794
Coffee and Spices,	2,683
Confectioners,	3,104
Copper, Brass, Etc.,	16,041
Cotton and Linen Mills,	99,256
Destructor Works,	1,891
Distillers and Brewers,	24,016
Dye Works and Bleacheries,	11,641
Electric Railways,	200,302
Electric Lighting,	233,283
Electrical Engineering and Supplies,	15,675
Export (not included under other headings),	42,508
Firearms and Ammunition,	4,772
Flour Mills and Bakeries,	20,697
Foundries,	6,064
Gas Works,	19,594
Glass Works,	10,886
Government Works,	16,407
Heating (Central Stations),	28,240
Heating and Power for Buildings,	85,256
Ice Making and Refrigerating,	11,336
Iron and Steel,	166,496
Jewelry,	650
Leather Works,	4,540
Locomotives, Boiler Makers, and Engines,	4,087
Lumber and Wood Working,	14,841
Machinery, Tools, and Hardware,	35,270
Mining,	104,237
Musical Instruments,	731
Oils, Paints, and Soap,	33,834
Packers and Canners,	5,479
Paper Mills,	31,069
Printers and Printers' Supplies,	6,851
Rope, Hemp, Etc.,	4,676
Sewing Machines,	10,860
Silk Mills,	4,257
Steam Roads,	11,652
Sugar Refiners,	121,863
Sugar Plantations,	70,009
Tobacco and Snuff,	4,141
Tube Works,	10,403
Unclassified,	27,238
Water Works,	37,151
Wire Works,	13,539
Woolen Mills,	22,446
Total Horse-Power,	1,709,813



United States Capitol, Washington, D. C. Heated and Lighted by 1484 H. P. Babcock & Wilcox Boilers. Erected 1889-1891, 1897-1900.

TABLE OF THIRTY-TWO TESTS OF BABCOCK & WILCOX WATER-TUBE BOILERS.

Owner of Plant Where Made.	Engineer Conducting Test.	Kind of Coal.	Date.	Duration, Hours.	Coal burned per square foot of grate per hour.	Water evaporated per square foot of heating surface per hour, from and at 212°.	Water evaporated per pound of coal, from and at 212°.	Water evaporated per pound of combustible, from and at 212°.	Per cent. of Refuse in Coal.	Draft.	Temperature of Flue Gases.	Per cent. of Moisture in Steam.	Ratio of Heating Surface to Grate.
Raritan Woolen Mills, Raritan, N. J., ...	Chas. E. Emery,	Lackawanna Chestnut, .	Feb. 5, 1879, . .	12.4	15.12	3.64	9.53	11.21	14.94	...	453°	1.05	39.61
Mill Creek Distillery, Cincinnati, O., ...	John W. Hill, . .	Pittsburgh 3d pool Lump,	Sept. 7, 1882, . .	10.0	27.5	4.55	10.47	11.0	4.81	Good	514°	4.62	63.37
Benedict & Burnham, Waterbury, Ct., ...	Wm. E. Crane, .	Anthracite Egg, . . .	March 12, 1883, .	22.0	16.34	3.46	9.90	11.37	12.9	...	325°	1.81	46.3
Oliver & Roberts Wire Co., Pittsburgh, Pa., . .	Wm. Kent, . .	Pittsburgh Lump, . . .	March 12 to 17, 1883,	114.00	24.14	3.39	9.71	10.91	11.0	...	400°	...	60.43
Arlington Cotton Mills, Wilmington, Del., . . .	Geo. H. Barrus,	Shamokin Pea, ...	May 9, 1883, . .	11	12.22	2.90	9.45	11.44	17.4	0.29	353°	...	39.6
Harrison-Havemeyer & Co., Philadelphia, Pa., .	Wm. Kent, . .	Anthracite Buckwheat, .	Oct. 31 to Nov. 3, '83,	72.0	13.76	2.92	8.81	10.88	19.13	...	365°	0.74	41.8
Rockland Mills, Wilmington, Del., ...	Wm. Kent, . .	Schuylkill Egg, ...	May 14 to 15, 1884,	24.0	10.23	2.30	9.58	11.03	13.20	0.16	336°	0.61	44.6
Lehman, Abrahams & Co., New Orleans, La., . .	Frederick Cook,	Pittsburgh, ...	May, 1884, . . .	11.0	18.02	4.42	10.63	11.24	5.4	...	520°	...	37.3
Croft & Allens, Philadelphia, Pa., ...	C. P. Higgins, .	Lehigh Valley Buckwheat,	Nov. 5, 1885, . .	10.5	15.7	3.30	9.35	11.58	19.32	.30	336°	...	44.
Cocheco Mfg. Co., Dover, N. H., ...	Geo. H. Barrus,	Lackawanna Broken, . .	June 26, 1886, . .	10.49	15.29	2.91	9.22	10.33	10.7	.13	360°	...	48.4
Cocheco Mfg. Co., Dover, N. H., ...	Geo. H. Barrus,	George's Creek, . . .	July 1, 1886, . .	10.73	16.32	3.45	10.27	10.98	6.4	0.21	428°	0.44	48.4
Providence Steam, Gas, & Pipe Co., Providence, R. I.,	Geo. A. Rowell,	Wilkesbarre Egg, . . .	April 17, 1889, . .	19.5	15.6	3.85	9.08	11.16	15.74	...	460°	...	37.0
Quaker City Dye Works, Philadelphia, Pa., . . .	J. M. Whitham,	Atlantic Clearfield, Pa., .	Aug. 2, 1893, . .	10	13.8	3.29	10.74	11.36	5.44	.22	478°	0.45	44.7
Berkshire Cotton Mills, Adams, Mass., ...	Wm. D. Hoxie,	Anthracite Egg, . . .	June 5, 1894, . .	10	11.94	2.75	10.68	12.1	12.0	.30	460°	0.60	46.35
Berkshire Cotton Mills, Adams, Mass., ...	Wm. D. Hoxie,	Reynoldsville, Pa., . .	June 6, 1894, . .	10	13.5	2.75	9.47	10.37	8.6	.38	500°	0.60	46.35
Acme Brewing Co., Macon, Ga., ...	J. M. Whitham,	Coal Creek, Tenn., . .	Nov. 15, 1894, . .	10	17.7	3.09	10.67	11.72	8.92	.30	400°	0.30	62.48
Hestonville, Mantua, & F. Park R. R., Philadel., Pa.,	J. J. DeKinder,	Henrietta, Pa., ...	March 29, 1895, .	9.50	28.92	6.34	10.28	10.97	6.32	.87	750°	0.12	46.87
Fairmount Worsted Mills, Philadelphia, Pa., . .	J. M. Whitham,	Lykens Valley Buckwheat,	June 11, 1895, . .	10	10.8	2.72	9.91	11.98	16.7	.28	400°	...	39.5
Royal Electric Co., Montreal, P. Q., ...	. . . .	Wierdale Lump, . . .	June 19, 1895, . .	8	16.54	3.35	9.47	10.21	7.28	.40	540°	...	46.35
German Hospital, Philadelphia, Pa., ...	J. M. Whitham,	Wyoming, Pa., Buckwheat,	Nov. 4, 1896, . .	10	16.14	3.12	9.91	11.92	16.9	.58	398°	0.70	51.3
Merrimack Mfg. Co., Lowell, Mass., ...	J. M. Whitham,	George's Creek, Md., .	March 5, 1897, . .	24	18.85	3.42	11.21	12.08	7.63	.35	516°	0.30	61.7
Set with Babcock & Wilcox Chain Grate Stoker.													
Singer Mfg. Co., Elizabethport, N. J., ...	Geo. A. Rowell,	Big Muddy, Ill., . . .	April 22, 1890, . .	7.75	23.61	3.69	8.16	9.40	13.27	.55	505°	...	54.2
American Sugar Refining Co., New Orleans, La., .	Geo. A. Rowell,	Cahaba, Ala., Slack, . .	Nov. 28, 1893, . .	10	26.55	3.89	9.25	10.32	10.33	.53	468°	...	60.6
American Sugar Refining Co., New Orleans, La., .	Geo. A. Rowell,	Pratt, Ala., Slack, . . .	Nov. 29, 1893, . .	10	26.35	4.37	10.05	11.54	12.96	.55	507°	...	60.6
Homestead Steel Works, Homestead, Pa., . . .	Geo. A. Rowell,	Poor quality Slack (53c. ton)	March 23, 1894, .	9	23.84	3.91	8.95	10.32	13.33	.37	449°	...	60.6
Flour Exchange, Minneapolis, Minn., ...	Wm. A. Pike, .	Youghiogheny Screenings,	July 26, 1894, . .	8	23.9	2.78	8.31	9.76	14.9	.30	436°	...	71.1
Duquesne Steel Works, Duquesne, Pa., ...	Danl. Ashworth, J. M. Whitham,	Connellsville, Pa., . . .	Jan. 25, 1895, . .	8	33.2	5.8	10.70	11.90	10.16	1.16	538°	0.55	61.3
S. D. Warren & Co., Cumberland Mills, Me., . .	J. M. Whitham,	Columbian, Va., . . .	July 10, 1895, . .	10	23.9	4.36	11.01	12.19	9.7	.51	388°	0.17	60.6
S. D. Warren & Co., Cumberland Mills, Me., . .	F. W. Dean, .	Pocahontas, Va., . . .	Sept. 17, 1895, . .	10	22.34	3.87	10.86	11.91	8.78	.38	361°	0.17	62.71
Tremont and Suffolk Mills, Lowell, Mass., . . .	E. H. Peabody,	New River, Va., . . .	March 26, 1896, .	8.50	23.11	4.06	10.94	11.83	7.5	.54	470°	...	62.2
Staten Island Electric R. R. Co., New Brighton, S. I.,	W. N. Sheaff, .	Victor, Pa., ...	May 28, 1897, . .	10	15.17	2.66	10.70	11.78	9.13	.48	485°	...	60.28

Coronado Beach Hotel, Coronado, Cal. Lighted and Heated by 720 H.P. of Babcock & Wilcox Boilers. Erected 1892 and 1902.

AVERAGE COST OF REPAIRS

OF BABCOCK & WILCOX BOILERS IN THE PAST SEVENTEEN YEARS.

The following facts are gathered from a large number of answers to a circular of inquiry sent to all our older customers. Sufficient replies were received to include over 100,000 horse-power, the repairs to the heating surface of which, due to all causes, have averaged less than 5 cents per horse-power per year, of 300 days at 12 hours per day; boilers which have run night and day being credited with the extra running time. The list would have been more complete, and made a still better showing, but for the fact that a number of our best customers declined to give facts pertaining to their business for publication.

DECASTRO & DONNER SUGAR REFINING CO. 2880 H.P. Average time, 13.6 years, night and day. Total repairs, 6c. yearly per H.P.

SINGER MANUFACTURING CO. (Case Factory), South Bend, Ind., 900 H.P. Average time, 12⅓ years. Total repairs, $\frac{4}{10}$c. yearly per H.P.

"Very bad feed-water.... carry heavy fires and force them beyond their rated capacity....in one instance we had to replace two heads and four tubes that were broken and blistered by a careless fireman *heating an empty boiler red hot, and then turning on the feed-water !!* Instead of a disastrous explosion that would have followed with other boilers, we lost the above parts and two days' time."
LEIGHTON PINE, Manager.

AMERICAN GLUCOSE CO., Buffalo, N. Y. 3050 H.P. Average time, 9.8 years. Total repairs, 4c. yearly per H.P.

NEW YORK STEAM CO. 13900 H.P. Average time, 3.92 years, night and day. Total repairs, ¾c. yearly per H.P.

ROSAMOND WOOLEN CO., Almonte, Ont. 360 H.P. Average time, 8⅓ years. Total repairs, 1$\frac{1}{10}$c. yearly per H.P.

BOUND BROOK WOOLEN MILLS. 600 H.P. Average time, 8.1 years. Total repairs, 2c. yearly per H.P.

RARITAN WOOLEN MILLS. 1060 H.P. Average time, 6.7 years. Total repairs, *nothing*.

E. C. KNIGHT & CO., Philadelphia. 2000 H.P. Average time, 5¼ years. Total repairs. 1c. yearly per H.P.

CONGLOMERATE MINING CO. 1800 H.P. Average time, 3 years. Total repairs, *nothing*.

"The boilers in every way come up to our highest expectations."
HENRY C. DAVIS, Pres't.

BOSTON SUGAR REFINING CO. 1250 H.P. Average time, 8½ years. Total repairs, 4$\frac{1}{10}$c. yearly per H.P.

"Were put in early in 1880; have been in constant use night and day ever since."

C. GILBERT, Des Moines, Iowa. 488 H.P. Average time, 5 years. Total repairs, 3$\frac{2}{10}$c. yearly per H.P.

BROOKLYN SUGAR REFINING CO. 3464 H.P. Average time, 7⅓ years, running night and day. Total repairs, 1¼c. yearly per H.P.

JOHN CROSSLEY & SONS, LIMITED, Plantation, Louisiana. 1260 H.P. Average time, 3⅓ years. Total repairs, *nothing*.

PORTAGE STRAW BOARD CO., Circleville, O. 1472 H.P. Average time, 3¼ years. Total repairs, 3$\frac{9}{10}$c. yearly per H.P.

"These boilers have been worked hard a great portion of time and have given good satisfaction."
JNO. L. TAFLIN, Manager.

BAY STATE SUGAR REFINING CO., Boston. 798 H.P. Average time, 7.3 years. Total repairs, $\frac{7}{10}$c. yearly per H.P.

"These boilers have been constantly driven at their highest capacity ever since their installation, until the present winter, and the cost of repairs to heating surfaces in that time has been $82.53."
J. F. STILLMAN, Supt.

WHEELER, MADDEN & CLEMSEN M'F'G CO., Middletown, N. Y. 244 H.P. Average time, 5 years. Total repairs, *nothing*.

"We think this a very good record, and are very much pleased with the boilers."

JOEL H. GATES, Burlington, Vt. 244 H.P. Average time, 5 years. Total repairs, *nothing*.

RUMFORD CHEMICAL WORKS. 279 H.P. Average time, 5 years. Total repairs, *nothing*.

"No expense on account of repairs to heating surfaces for either of them, since they were put in."
N. D. ARNOLD, Treas.

TYTUS PAPER CO., Middletown, O. 650 H.P. Average time, 6 years, night and day. Total repairs, 6½c. yearly per H.P.

SOLVAY PROCESS CO., Syracuse, N. Y. 3456 H.P., from 6 to 1½ years. Average time, 2.6 years, night and day. Total repairs, 1½c. yearly per H.P.

"The only repairs we have had to make are for new tubes when they have been burnt out. As you are well aware the water which we use at Syracuse is very hard upon boiler tubes, and we suppose we have burnt out more on this account than if the water had been good."
F. R. HAZARD, Treas.

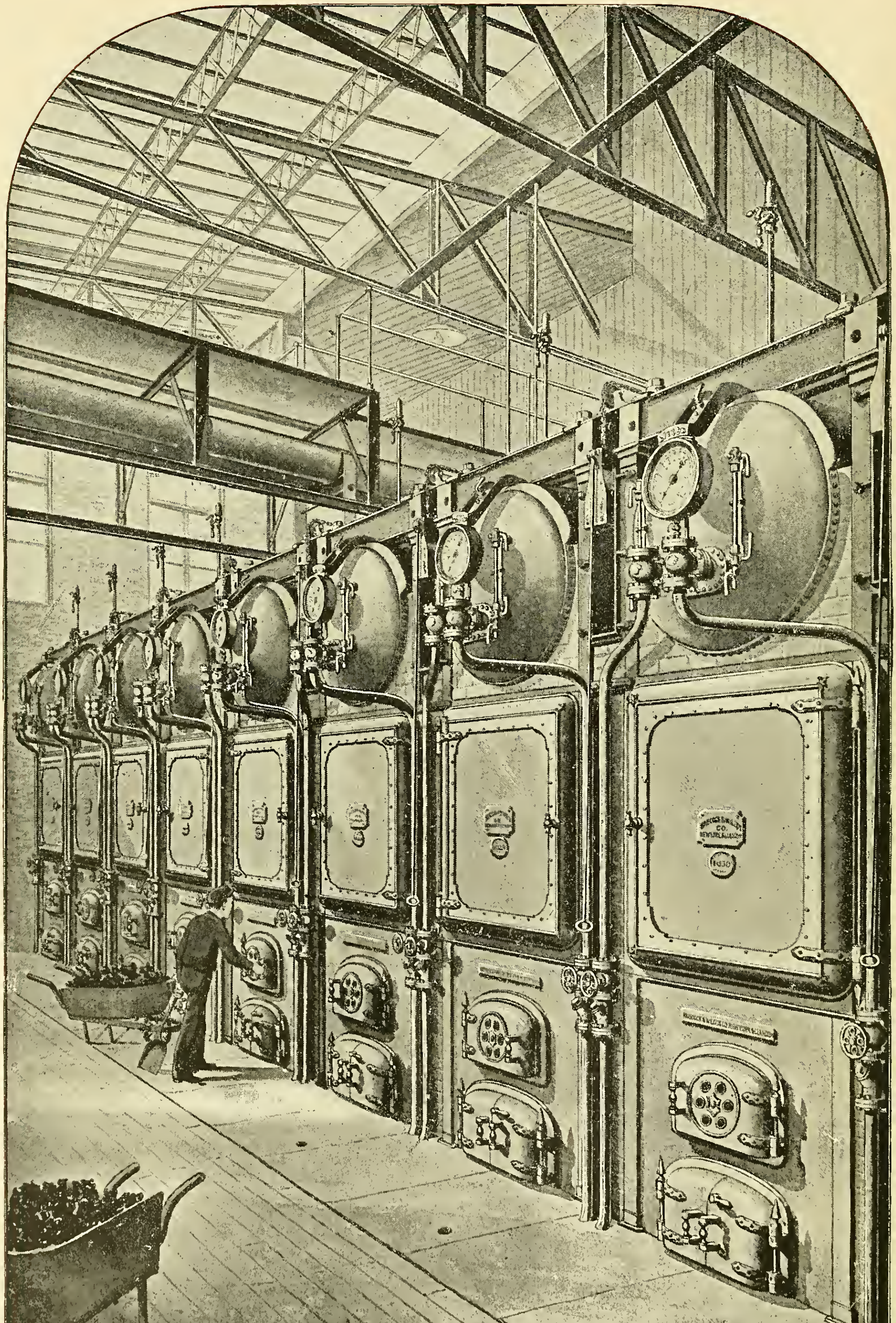
"I believe our repairs would have been greater had we used the tubular type of ordinary design."
W. B. COGSWELL, Manager.

THE WARDLOW THOMAS PAPER CO., Middletown, O. 600 H.P. Average time, 6 years. Total repairs, *nothing*.

"Easily managed, economical in coal, attendance, and repairs; and the element of safety under our hard firing is a source of much satisfaction to us."
O. H. WARDLOW, Pres't.

W. A. WOOD, M. & R. M. CO. 360 H.P. Average time, 4$\frac{6}{10}$ years. Total repairs, 1$\frac{2}{10}$c. yearly per H.P.

"We consider them as good as new to-day, and can recommend them as economical both in repairs and fuel."
J. M. ROSEBROOKS, Sup't.



Babcock & Wilcox Boilers at Imperial Continental Gas Association, Vienna. 972 H.P. "W.I.F." Style, Wrought Headers.

MARCUS MOXHAM & CO., Swansea, Wales. 104 H.P. Average time, 3¾ years.

"It has not cost us a penny for repairs."

LAING, WHARTON & DOWN, *Electricians*, London. 85 H.P. Average time, 2.3 years.

"As regards repairs they have got to come, as they have not yet cost anything."

CARNEGIE BROTHERS & CO., Pittsburgh, 900 H.P. Average time, 5 years. Total repairs, $1\frac{1}{10}$c. yearly per H.P.

"The total repairs to heating surfaces in that time have been $50." CARNEGIE BROS. & CO.

RANSOMES, SIMS & JEFFERIES, L'd, Ipswich, England. 35 H.P. Average time, 4½ years. Total repairs, *nothing*.

"The repairs appear to have been about £7 for brick-work." RANSOMES, SIMS & JEFFERIES, L'D.

CROCKER CHAIR CO., Sheboygan, Wis. 225 H.P. Average time, 7 years. Total repairs, 1c. yearly per H.P.

"The total cost of repairs to heating surfaces in that time has been not to exceed $15. We do not hesitate to say that it is the best boiler we have ever used."

EAGLE PAPER CO., Franklin, O. 250 H.P. Average time, 4¾ years. Total repairs, 22c. yearly per H.P.

"We are well pleased with them."
D. B. ANDERSON, Manager.

FIELDHOUSE & DUTCHER MANUFACTURING CO., Chicago. 75 H.P. Average time, 6 years. Total repairs, $11\frac{1}{10}$c. yearly per H.P.

"Consider your boiler to be the most economical and best made."

LOUISIANA SUGAR REFINING CO. 960 H.P. Average time, 5½ years.

"The cost of repairs is very moderate."
JOHN S. WALLIS, Pres't.

NORTH BEND PLANTATION, Louisiana. 400 H.P. Average time, 10 years. Total repairs, 11¼c. yearly per H.P.

FRANCIS AXE CO. 136 H.P. Average time, $5\frac{3}{10}$ years. Total repairs, *nothing*.

WELHAM ESTATE, Louisiana. 240 H.P. Average time, 2 years. Total repairs, *nothing*.

"I have used the boiler with perfect satisfaction."
WM. E. BRICKELL, Agent.

JOSEPH SCHOFIELD & CO., Littleboro, Manchester. 156 H.P. Average time, 2¾ years. Total repairs, 1½c. yearly per H.P.

SETH THOMAS CLOCK CO. 125 H.P. Average time, 7 years. Total repairs, *nothing*.

"The only cost has been the amount spent on account of burning up of fire-box furnace brick."

WALLACE & SONS. 400 H.P. Average time, 7 years. Total repairs, $\frac{7}{10}$c. yearly per H.P.

"They are apparently in perfect condition now."

FOSS & BARNETT. 125 H.P. Average time, 7 years. Total repairs, *nothing*.

"Have not cost one dollar for repairs—simply new grate bars. Think they are good economical boilers."

CORTLAND WAGON CO. 82 H.P. Average time, 6 years. Total repairs, *nothing*.

"No outlay for repairs. We consider this remarkable because we have forced the boiler from the beginning.

EAGLE SQUARE MANUFACTURING CO., South Shaftsbury, Vt. 200 H.P. Average time, 5½ years. Total repairs, *nothing*.

"Have purchased a few fire brick to go between tubes. We have found no other repairs necessary."
F. L. MATTISON, Treas.

PAINE LUMBER CO., Oshkosh, Wis. 416 H.P. Average time, 4 years. Total repairs, *nothing*.

"Have been using the ordinary boilers with both large and small tubes for thirty years past, and regard your boilers as more economical."
PAINE LUMBER CO.—A. B. Ideson.

P. P. MAST & CO., Springfield, O. 85 H.P. Average time, 8½ years, night and day. Total repairs, $3\frac{4}{10}$c. yearly per H.P.

"We regard it as the best boiler ever used by our Company, and think it has no equal in the market. After all this hard usage, equal to 14 years, we find it still in good condition." P. P. MAST & CO.

EDISON ELECTRIC ILLUMINATING CO. of Piqua, O. 100 H.P. Average time, 5¼ years. Total repairs, $4\frac{7}{10}$c. yearly per H.P.

HALLET & DAVIS CO., Boston. 104 H.P. Average time, 6 years. Total repairs, 5c. yearly per H.P.

"Our repairs to boiler have been for new nipples in mud-drum in Aug., 1887, which is certainly a very creditable showing." HALLET & DAVIS CO.

H. D. SMITH & CO., Plantsville, Conn. 75 H.P. Average time, 8 years. Total repairs, *nothing*.

"We know of no other boiler that would do the work that this is doing." H. D. SMITH & CO.

F. A. POTH BREWING CO., Philadelphia. 400 H.P. Average time, 4 years. Total repairs, $1\frac{3}{10}$c. yearly per H.P.

J. L. CLARK, Oshkosh, Wis. 107 H.P. Average time, 6½ years. Total repairs, $\frac{7}{10}$c. yearly per H.P.

"Develop at least one-third more work than rated. We cannot speak too highly of your boilers. They are simply perfect." J. L. CLARK.

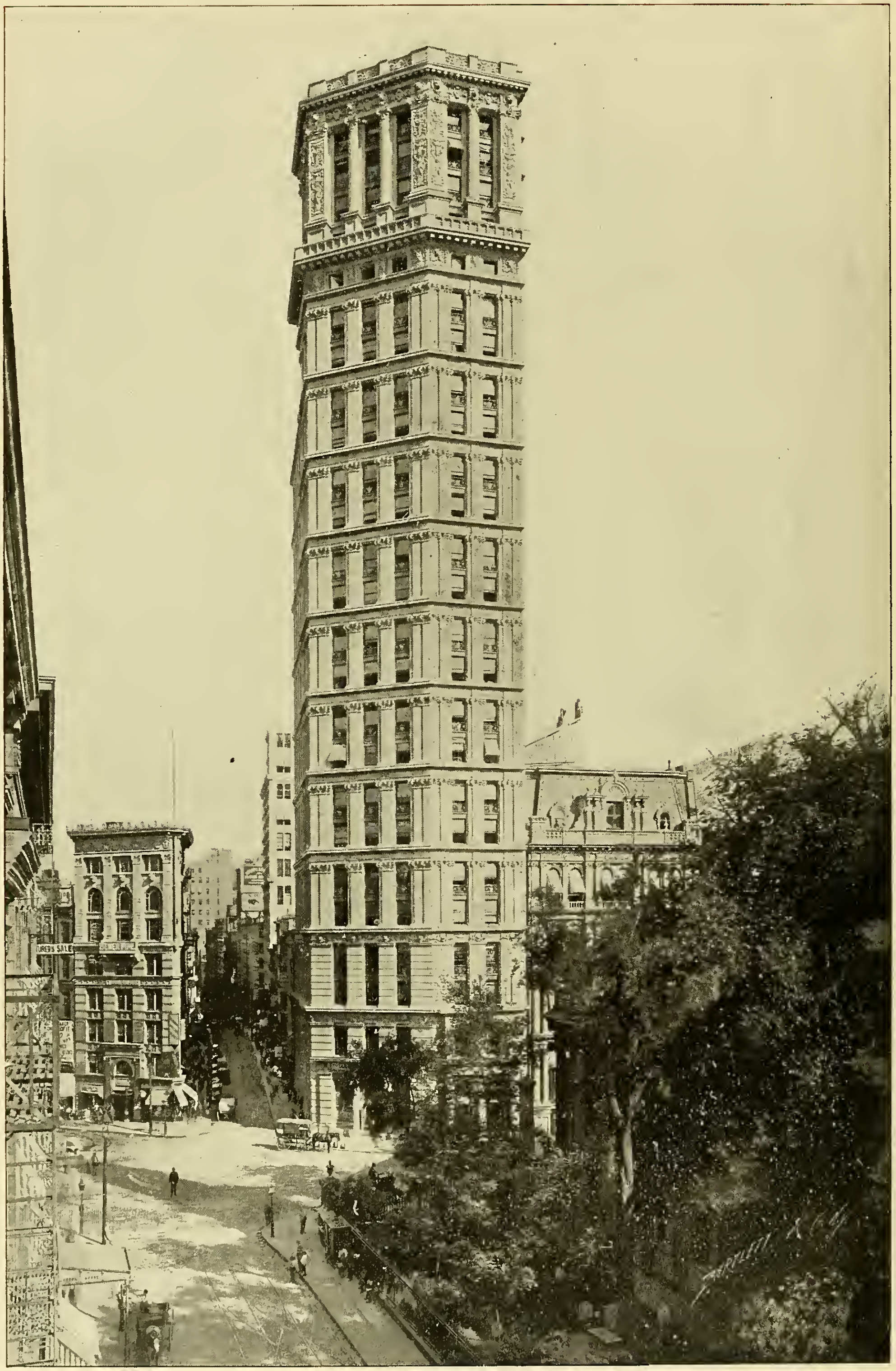
SOCIETÀ GENERALE ITALIANA DI ELETTRICITA, SISTEMA EDISON, Milan, Italy. 1476 H.P. Average time, 3½ years.

"The repairs have consisted in the changing of 4 tubes and about 220 rivets (not counting the last accident due to carelessness of the firemen)".
L'Amministratore Delegato—J. COLUMBA.

UNION IRON WORKS, Johnstone, Scotland. 104 H.P. Average time, 5 years. Total repairs, 3c. yearly per H.P.

P. & P. CAMPBELL, Perth, Scotland. 146 H.P. Average time, 2 years.

"The boilers have cost nothing for repairs themselves, but the doors and furnace have cost about £4 10s. per annum." P. & P. CAMPBELL.



St. Paul Building, New York. 420 H.P. Babcock & Wilcox Boilers.

CHENEY BROS., So. Manchester, Conn. 350 H.P. Average time, 7 years.

"Running steadily for seven years, and during that time they have not cost us anything for repairs to the heating surfaces." CHENEY BROS.

TOLEDO & OHIO CENTRAL R. R. 120 H.P. Average time, $7\frac{2}{3}$ years. Total repairs, $12\frac{8}{10}$c. yearly per H.P.

"The boilers have given entire satisfaction in every respect." J. B. MORGAN, Master Mechanic.

MCAVOY BREWING CO., Chicago. 832 H.P. Average time, 6 years. Total repairs, 10c. yearly per H.P.

"Our experience with them has been to our entire satisfaction." GEO. DICKINSON, Sec'y.

(NOTE.—One-half of total expense was due to broken headers caused by low water, because of water combination becoming shut off.)

CORNWALL BROS., Louisville, Ky. 227 H.P. Average time, $8\frac{1}{4}$ years. Repairs, *nothing*.

MAGINNIS COTTON MILL, New Orleans. 624 H.P. Average time, 6 years. Total repairs, $1\frac{6}{10}$c. yearly per H.P.

PIONEER MILLS. 150 H.P. Average time, $9\frac{1}{3}$ years. Total repairs, "slight."

"Cost of repairs comparatively nothing. No leaking of flues or boiler at any time." J. A. M. JOHNSTON, Agent.

LAWRENCE ROPE WORKS, Brooklyn. 250 H.P. Average time, 7 years. Total repairs, 4c. yearly per H.P.

JAMES MARTIN & CO., Philadelphia. 208 H.P. Average time, $7\frac{3}{10}$ years. Total repairs, 16c. yearly per H.P.

"There has been but little cost for repairs to them, those we have made being for a few new tubes that became clogged or coated with scale on account of the *very* hard (*well*) water we are using. We cannot speak too highly of them." JAS. MARTIN & CO.

FAIRMOUNT WORSTED MILLS, Philadelphia. 400 H.P. Average time, 7.5 years. Total repairs, $6\frac{8}{10}$c. yearly per H.P.

WM. WHITAKER & SONS, Philadelphia. 480 H. P. Average time, 7 years. Total repairs, *nothing*.

VANDERBILT UNIVERSITY, Nashville, Tenn. 200 H.P. Average time, 6 years. Total repairs, 4c. yearly per H.P.

"Cost of repairs to heating surface on all the above during that time has been $48.25. The boilers during that time have given entire satisfaction." OLIN H. LANDRETH, Dean of Engineering Dept.

ARLINGTON MILLS MANUFACTURING CO. 500 H.P. Average time, 8 years. Total repairs, *nothing*.

SOMERSET MANUFACTURING CO., Raritan, N. J. 720 H.P. Average time, 7.5 years. Total repairs, *nothing*.

NEW YORK & BROOKLYN BRIDGE. 600 H.P. Average, $2\frac{1}{3}$ years. Total repairs, *nothing*.

"The boilers have done excellent service and have given entire satisfaction." C. C. MARTIN, Ch. Eng. & Supt.

CHURCH & CO., Brooklyn, E.D. 584 H.P. Average time, 4.2 years. Repairs, *nothing*.

ECONOMIST PLOW CO., South Bend, Ind. 150 H.P. Average time, 5 years. Total repairs, *nothing*.

"We believe it to be the most durable boiler made." LEIGHTON PINE, Pres't.

UNION METALLIC CARTRIDGE CO., Bridgeport, Conn. 276 H.P. Average time, $4\frac{1}{3}$ years. Total repairs, *nothing*.

"The cost of repairs to heating surfaces of said boilers in that time has been nothing. We carry from 75 to 80 lbs. all the time." A. C. HOBBS, Supt.

WARDER, BUSHNELL & GLESSNER CO. 650 H.P. Average time, $3\frac{1}{4}$ years. Total repairs, $4\frac{6}{10}$c. yearly per H.P.

"The boilers are giving us the best satisfaction." CHAS. A. BAUER, Gen'l Manager.

CHICAGO CITY RAILWAY CO. 1000 H.P. Average time, 7 years, night and day. Total repairs, $4\frac{8}{10}$c. yearly per H.P.

"The boilers have worked well and proved very satisfactory." C. B. HOLMES, Sup't.

SHEBOYGAN MANUFACTURING CO. 333 H.P. Average time, 8 years. Total repairs, 4c. yearly per H.P.

"We have found them economical, easily kept in running order, and in all ways entirely satisfactory, and should we need additional power would use no other boilers." G. L. HOLMES, Pres't and Gen'l Manager.

JACKSON & SHARP CO., Wilmington, Del. 467 H.P. Average time, $5\frac{7}{10}$ years. Total repairs, $1\frac{7}{10}$c. yearly per H.P.

"Have cost *nothing* for repairs to heating surfaces, except through the carelessness of our fireman, who, soon after starting the first boilers, allowed the water to get too low and burst three or four headers, but doing no other damage. We consider them safe and economical steam generators." THE JACKSON & SHARP CO., by Chas. S. Robb.

SOUTH BEND TOY MANUFACTURING CO. 61 H. P. Average time, 4 years. Total repairs, $2\frac{1}{2}$c. yearly per H.P.

"We consider these boilers the safest and most economical in the market." F. H. BADET, Sec. & Treas.

COLUMBUS BUGGY CO., Columbus, O. 800 H. P. Average time, 7 years. Total repairs, $1\frac{8}{10}$c. yearly per H.P.

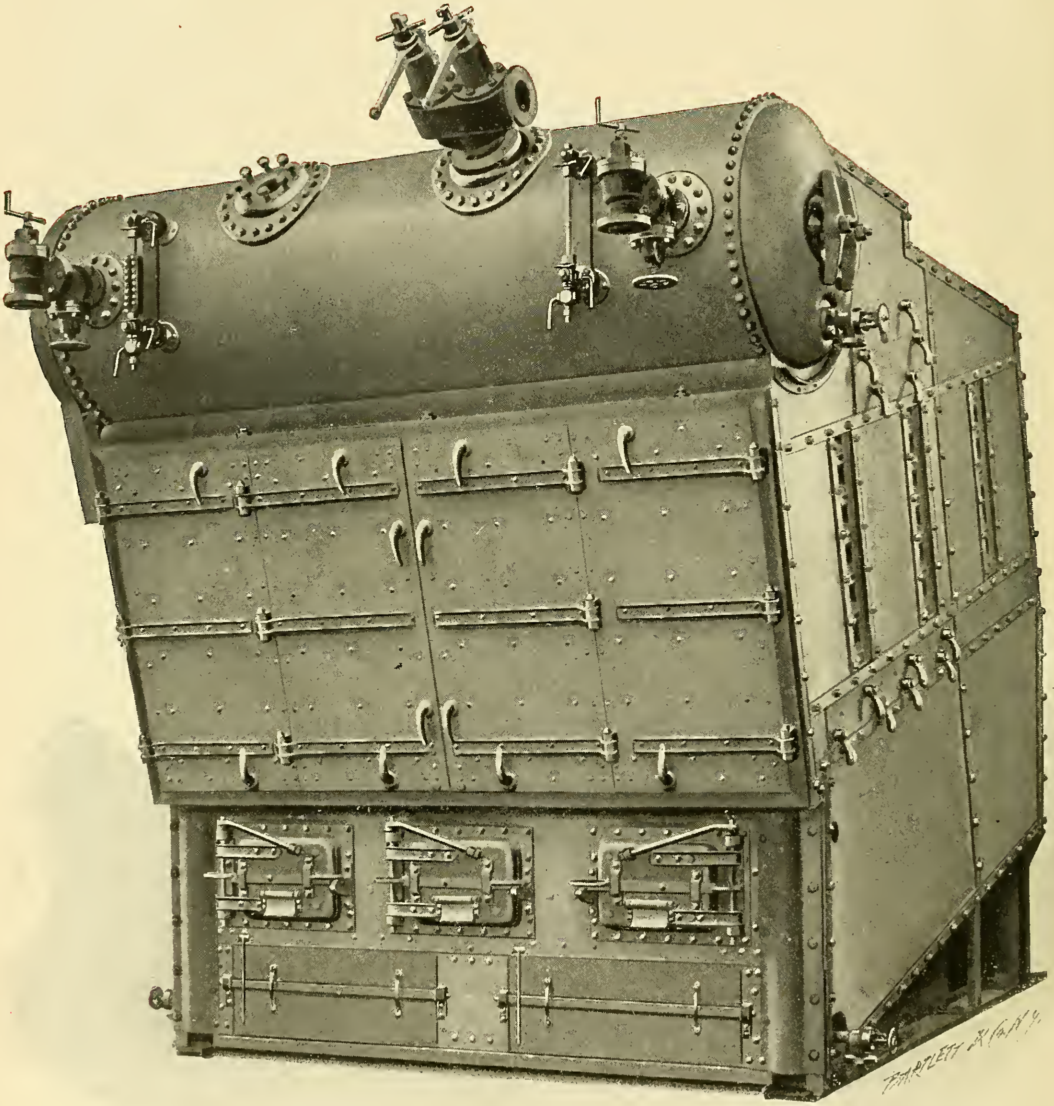
"We consider them the best boiler in the market and we are now evaporating 9 lbs. of water to one pound of poor slack coal." FRED. WEADON, Supt.

EDISON ELECTRIC ILLUMINATING CO. OF N. Y. 900 H.P. Average time, 7 years. Total repairs, *nothing*.

"They give plenty of dry steam and have been absolutely tight at all times. The boilers have shown unusual ability to carry a constant pressure under the extreme and sudden fluctuations, which are unavoidable in an electric light station." C. E. CHINNOCK, V. Pres.

KENNESAW MILLS CO., Marietta, Ga. 200 H. P. Average time, 7 years. Total repairs, $2\frac{3}{10}$c. yearly per H.P.

"You will see that the repairs on our boilers have not cost very much for the last 7 years." J. R. BUCHANAN.



Babcock & Wilcox Marine Water Tube Boiler.

E. Greenfield's Son & Co., Brooklyn. 160 H.P. Average time, 4 years.

"They show no signs of wear, therefore probably will not need repairing for some time to come. We consider them the best boilers we have ever used."

Black & Germer, Erie, Pa. 92 H.P. Average time, 4 years. Total repairs, *nothing*.

"Is easily cared for and economical in the consumption of fuel."

Planters Sugar Refining Co., New Orleans. 292 H.P. Average time, 6 years. Total repairs, *nothing*.

"The only expense attached to them has been new grate bars and fire brick work." John Barkley, Pres't.

S. S. Hepworth, Yonkers, N. Y. 104 H.P. Average time, $4\frac{5}{12}$ years.

"During all this time it gave no trouble whatever, and did not cost one penny for repairs."

Wilson & McCallay Tobacco Co. 300 H. P. Average time, 5 years. Total repairs, $4\frac{1}{3}$c. yearly per H.P.

John Collins, Denny, North Britain. 425 H. P. Average time, $3\frac{4}{10}$ years.

"The repairs to heating surfaces have been slight, and caused by an unfortunate admission of grease to feed water in the case of my 140 H.P. boiler. With this exception, which of course arose from no fault of yours, the boilers have done good and heavy work and given me satisfaction." John Collins.

Singer Manufacturing Co., Kilbowie, Scotland. 2106 H.P. Average time, $4\frac{1}{2}$ years. Total repairs, $\frac{1}{6}$c. yearly per H.P.

"We have much pleasure in sending you particulars of boilers as requested. . . . Total repairs, £3. 19. 3, which we consider highly satisfactory."

Nova Scotia Sugar Refinery, Halifax, N. S. 800 H.P. Average time, $7\frac{3}{4}$ years, night and day. 600 H.P. since 1880; 200 in 1885. Total repairs, $1\frac{1}{2}$c. yearly per H.P.

"We have pleasure in saying we consider them first-class boilers in every respect." J. A. Turnbull, Man.

Kennedy's Patent Water Meter Co. L'd., Kilmarnock, Scotland. 51 H.P. Average time, 6 years. Total repairs, *nothing*.

"Repairs confined to re-expanding one tube. The cost was trifling." Thos. Kennedy.

Bent Colliery Co. L'd. Bothwell, Scotland. 480 H.P. Average time, $4\frac{8}{10}$ years.

"The cost of repairs during that time has been trifling. I think two short tubes were renewed. The boilers have been constantly at work." Jas. S. Dixon.

Corporation of Aberdeen Gas Works, Scotland. 93 H.P. Average time, 3 years, night and day. Total repairs, *nothing*.

"The boiler continues to give great satisfaction." Alex. Smith.

The Square Works, Ramsbottom, England. 136 H.P. Average time, 4 years, night and day. Total repairs, $9\frac{8}{10}$c. yearly per H.P.

"Since Feb. 5th, 1884, night and day work, 16/6 except the breakdown through being short of water, which cost £21.17.4 to repair." Hepburn & Co.

Whitmore & Sons, Edenbridge, Kent, England. 100 H.P. Average time, 3 years.

"Have not spent one penny on the boiler."

Miller & Co., Foundry, Edinburgh, Scotland. 240 H.P. Average time, 3 years. Total repairs, *nothing*.

"Only expense has been some repairs to the brickwork in connection with the stoker." Miller & Co.

Carthness Steam Saw Mill, Wick, Glasgow. 146 H.P. Average time, $2\frac{1}{2}$ years. Total repairs, *nothing*.

"We are well pleased with your boilers, and can with confidence recommend them to any firm wishing to economize their working expenses." Alex. McEwen.

Georgie Mills, Edinburgh, Scotland. 146 H. P. Average time, $3\frac{1}{2}$ years, night and day. Total repairs, *nothing*.

"Neither boiler has required any repairs to heating surfaces." J. & G. Cox.

J. & T. Boyd, Iron Works, Glasgow. 208 H.P. Average time, $2\frac{6}{10}$ years.

"One of these has worked nearly 5 years and the other about half that time without any repairs whatever."

Dubois & Charvet-Colombier, Armentières, France. 476 H.P. Average time, 3 years.

"These boilers have worked to our entire satisfactiou since 2d November, 1885, without as yet any repairs whatever."

Arrol Brothers, Bridge Builders, Glasgow. 146 H.P. Average time, $5\frac{2}{3}$ years.

"Cost of repairs to heating surface is as yet nothing. It gives us pleasure to hand you this information, which is entirely at your own disposal." Arrol Bros.

James Eadie & Sons, Tube Works, Glasgow. 64 H.P. Average time, 5 years.

"Repairs to heating surfaces, none."

Hughes & Son. Meole Brace, Shrewsbury, England. 61 H.P. Average time, 4 years.

"Has up to now cost us nothing whatever for repairs. We can only repeat that we are very much pleased in every respect with your boiler."

Westinghouse Air Brake Co., Pittsburgh. 92 H.P. Average time, $4\frac{1}{2}$ years. Total repairs, 4c. yearly per H.P.

"The repairs have been merely nominal, being confined to the re-expanding of a few tubes and the replacing of two or three hand hole covers, at a total cost probably not exceeding $15. The boiler has given entire satisfaction." H. H. Westinghouse, General Manager.

Carthage Water Works. 122 H.P. Average time, $6\frac{1}{2}$ years. Total repairs, *nothing*.

"They are practically as good as when we put them in; there is not a blister or scale on the tubes. The fire has not been out since we first started up in January, 1882." C. S. Bartlett, Manager.

J. Pongs, Jr., Newerk, Germany. 120 H.P. Average time, 3 years.

"Has been running 3 years without needing any repairs up to this time." J. Pongs, Jr.

Carron Co., Carron, Stirlingshire, N.B. 416 H.P. Average time, 4 years. Totai repairs, *nothing*.

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